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FINAL REPORT, VOLUME 3
EXPERIMENTAL DETERMINATION OF THE HEAT TRANSFER IN THE VAPOUR SPACE OF A PARTIALLY FILLED HORIZONTAL CYLINDER

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17. Abstract

Knowledge of heat transfer coefficients in the vapour space in rail tank cars is of importance since tank rupture is usually initiated in this region. The purpose of this thesis is to obtain vapour heat transfer coefficients of a partially filled horizontal cylinder with and without an internal protection system (Explosafe) under simulated fire conditions, using a constant electrical power input. Wall and vapour temperatures as well as pressure histories as a function of time were obtained for a partially filled horizontal cylinder of Freon-11. Heating of the vessel from 10 to 65 kW/m^2, with three liquid levels (76, 58 and 23%) and two pressure relief valve (PRV) orifice diameters (6.4 mm and 9.5 mm) permitted fluid behaviour observation and estimation of the vapour space heat transfer coefficients. The data obtained correlated well with data from earlier full-scale and one-fifth scale field tests.

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17. Résumé

Il est important de connaître les coefficients de transfert de chaleur dans la vapeur à l'intérieur d'un wagon-citerne car la rupture d'un réservoir se fait normalement dans la partie où est emprisonnée la vapeur. Cette étude cherche à déterminer les coefficients de transfert de chaleur dans la vapeur d'un cylindre horizontal partiellement rempli, avec ou sans dispositif de protection interne (Explosafe), et exposé à la chaleur d'un générateur électrique simulant l'effet des flammes. Les températures de la paroi et de la vapeur ainsi que la pression de cette dernière en fonction du temps ont été déterminées pour un cylindre horizontal partiellement rempli de fréon-11. En chauffant le réservoir à une puissance surfacique allant de 10 à 65 kW/m^2, à trois niveaux de remplissage (76, 58 et 23%) et avec deux diamètres d'orifice (6,4 et 9,5 mm) pour les soupapes de sûreté, nous avons pu observer le comporetement des fluides et évaluer les coefficients de transfert de chaleur dans la vapeur. Les valeurs obtenues sont en bonne concordance avec les valeurs mesurées précédemment dans des tests sur des wagons-citernes et sur des modèles réduits à échelle un cinquième.

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LIST OF SYMBOLS

A	surface area (m^2)
A_h	heated area in the vapour space (m^2)
C_d	valve discharge coefficient
C_p	specific heat at constant pressure (J/kg.K)
D	diameter of the transfer line (m)
dr	radial distance between the wall and the top most thermocouple (m)
F	view factor
G_v	mass flux of vapour (kg/m^2 sec)
g	acceleration due to gravity (m/sec^2)
h_{fg}	latent heat of vaporisation (kJ/kg)
h	heat transfer coefficient ($W/m^2.K$)
h_g	constant heat transfer coefficient of the gas ($W/m^2.K$)
k	thermal conductivity (W/m.K)
K_θ	dimensionless velocity correction factor for non-vertical transfer lines
L	length of the transfer line (m)
L_c	characteristic length (m)
m	rate of vapour generation (kg/sec)
m_v	mass flow rate of vapour (kg/sec)
m	mass (kg)
N_g	geyser index

LIST OF SYMBOLS - Continued

P	pressure (N/m^2)
Q	total heat input per unit time (kW)
Q_C	conduction heat transfer in the vapour space (W/m^2)
Q_{RLA}	radiation heat transfer from the heater wire to Lava blocks (W/m^2)
Q_{CONDG}	conduction heat transfer through the gap between Lava blocks and the outer surface of the inner shell filled with argon gas (W/m^2)
Q_{IN}	total heat flux to the vapour space (W/m^2)
Q_{RE}	radiation heat transfer from the external surface to the surroundings (W/m^2)
Q_{RS}	radiation heat transfer from the heater wire to the outer surface of the inner shell (W/m^2)
Q_{RI}	radiation heat transfer from the vapour space wall to the liquid surface (W/m^2)
Q_{ST}	heat stored in the vapour space wall (W/m^2)
Q_{CONV}	convective heat transfer (W/m^2)
Q_{COND}	circumferential conduction heat transfer in the tank wall from the vapour space to the liquid space at the interface (W/m^2)
Q_{RELS}	radiation heat transfer from the Lava surface to the outer steel shell in the UNB tank (W/m^2)
Q_{LA}	heat absorbed by Lava blocks for heaters (W/m^2)
q	heat flux applied on the transfer line (kW/m^2)
q_f	heat flux extracted due to geysering (W/m^2)

LIST OF SYMBOLS - Continued

q_v	total heat supplied to the vapour space (W/m^2)
r	radius of the vessel (m)
R	gas constant (J/kg.K)
T	temperature (°C, K)
TLAV	average Lava temperature (°C)
T_{WV}	vapour space wall temperature specified at an angle with the vertical (°C)
T_{WL}	wall temperatures below the liquid level near the interface, specified at an angle with the vertical (°C)
T_{WVAV}	average temperature of vapour space wall (°C)
T_{WIRE}	temperature of the heater wire (°C)
T_{w_i}	initial lumped wall temperature (°C)
T	average temperature (°C)
t	thickness (m)
V	specific volume (m^3/kg)
V_v	volume of vapour (m^3)

Greek Letters

β	coefficient of thermal expansion (1/K)
Δh	latent heat of vaporization (kJ/kg)
ΔT	temperature difference (°C, K)
ϵ	emissivity
μ	dynamic viscosity (kg/m.sec)
ρ	density (kg/m^3)
τ	time (sec)
σ	Stefan Boltzman constant ($5.669 \times 10^{-8}\ W/m^2.K^4$)

LIST OF SYMBOLS - Continued

Dimensionless Numbers

Fo	Fourier number, $k_s \tau / \rho_s C_{p_s} t_s^2$
Nu	Nusselt number, hL_c / k_v
N_{COND}	modified condensation number, $L_c^3 g \rho_v^2 h_{fg} / \mu_v k_v (T_W - T_V)$
N_{Jm}	modified Jakob number, $\rho_f C_{p_f} T_{sat} / \rho_g h_{fg}$
Ra	Rayleigh number, $L_c^3 g \beta \rho_v^2 C_{p_v} \Delta T / \mu k$

Subscripts

L,f	liquid
m	mean
W	inside vapour wall
LA	Lava housing for heaters
SS	external steel shell in the UNB tank
s	steel wall
v,g	vapour or gas
o	stagnation condition
sat	saturated condition
WO	outside wall surface
WI	inside wall surface

Superscripts

1	initial condition
n	time level, $(n = 0,1,2,3,\ldots,n)$

CHAPTER 1

INTRODUCTION

1.1 Introduction

Railroad tank cars transporting such hazardous fluids as propane, ammonia, chlorine and other fluids, have been involved in a rising number of accidents. These accidents have caused death, serious injury and extensive property damage.

In a typical accident, a tank car carrying propane is punctured due to derailment or impact. The propane is released and subsequently ignited by sparks or a hot car component, (e.g. a hot brake). This results in a pool fire which engulfs other tank cars. These cars in turn are heated and unless properly vented by means of suitably sized pressure relief valves or otherwise somehow protected, will fail and explode [1].

In order to understand the physical behaviour of fluids inside tanks under fire accident conditions, the U.S. Department of Transportation has conducted field tests on unprotected partially filled full size LPG rail tank cars [2]. The Transport Development Centre (TDC) of Transport Canada has also conducted field tests on 1/5th linear scale unprotected and protected tanks [3]. In almost every accident and field test, tank rupture is usually due to the vapour space wall failure. This is because extremely high wall temperatures in the vapour space cause a reduction in the strength of the tank wall.

In this thesis therefore an experimental simulation of such an accident and the determination of the vapour space heat transfer in the tank car will be described.

The sequence of events in the vapour space may be described as follows (Fig. 1.1);

As the fire or heating starts [2, 3], some of the initial surge of heat is stored in the tank wall, Q_{ST}, and the rest is transferred into the vapour space. Conduction and free convection start adjacent to the wall in the vapour space upon the increase of the wall temperature above the bulk vapour temperature. Initially heat radiated from the external wall to the surroundings, Q_{ST}, and heat radiated from the vapour space wall to the liquid surface, Q_{RI}, are small, however, these increase as time progresses due to rising wall temperatures. The wall temperature causes radiation from the wall, and circumferential conduction in the wall from the vapour space to the liquid space, Q_{COND}, since heat transfer coefficients here are very much greater. Thermal stratification occurs in both the liquid and vapour. This stratification results due to non-uniform fluid density caused by the vertical temperature variation.

The pressure in the vessel will increase due to liquid thermal stratification until the pressure relief valve (PRV) set pressure is reached and the PRV opens. Super-heated vapour followed by a two-phase mixture may then flow through the PRV. During this discharge forced convection in the vapour space occurs along with two-phase swelling of the fluid resulting in some cooling of the vapour space walls.

As pressure is relieved, the PRV may close with vapour stratification again resulting with the vapour space heat transfer coefficient "h" rapidly decreasing from that under vented conditions. With continuing fire exposure or electrical heating, Q_{IN}, wall and vapour temperatures continue to increase despite valve action. Vapour stratification becomes more pronounced despite the forced convection due to fluid flow. The vapour space wall temperatures continue to increase as the fluid level changes and mass exits through the valve. A stage may eventually be reached when the tank wall ruptures and a "BLEVE" (Boiling liquid expanding vapour explosion) occurs.

Other workers [3] have investigated the potential of an internal protection system (Explosafe) for use as a thermal diffuser and explosion suppressant in such tanks. The modes of heat transfer in the vapour space of an Explosafe equipped vessel are similar to those above for the unprotected vessel. The internal heat radiation from the vapour space wall to the liquid surface is, however, greatly reduced due to very low emissivity of polished aluminum foil mesh (Explosafe).

The internal vapour space wall may also be protected by the introduction of the two-phase fluid boiling on the inner surface with a geyser or fluid expulsion cooling system [5, 6]. Geysering is the rapid expulsion of liquid from the fluid transfer line as a result of vapour generation within the line at a rate in excess of that which could be released by normal bubble buoyancy. The expelled two-phase fluid can thus absorb heat from hot surfaces by evaporation and hence reduce wall temperatures significantly.

The objectives of the present investigation are therefore to experimentally study for an externally heated partially filled horizontal cylinder:

1) the heat transfer in the vapour space with no internal protection;
2) the heat transfer in the vapour space with Explosafe as an internal protection system; and
3) the effects of the PRV orifice area on the vapour and wall temperatures and vapour stratification in the vapour space.

An initial attempt is additionally made

a) to develop an empirical relation to correlate the experimental vapour space heat transfer data; and

b) to determine the possibility of using a geysering system as a protection system to cool the vapour space wall.

1.2 Literature Review

From the above, work in two areas needs to be considered;

1) experimental investigations of transient heat transfer in partially filled horizontal cylinders; and
2) the geysering phenomenon as a protection mechanism for the vapour space.

1.2.1 Heat Transfer in Partially Filled Horizontal Cylinders

Anderson et al. [2] conducted a field test on a full-sized partially filled liquified petroleum gas (LPG) rail tank car, exposed to a JP-4 fuel fire environment. The tank car was 18.3 m long and 3.05 m in diameter. The steel shell was constructed of 1.59 cm thick TC-128 mild steel. The test provided data on the fire environment, the rate and mechanism of heat transfer into the lading, the operating of the pressure relief valve in a fire environment and the torching effect of the relief valve on the tank wall. In addition, the wall, vapour and liquid temperature profiles along with the external circumferential fire temperature distributions were also obtained.

Appleyard [3] reported a series of fire engulfment tests on partially filled 1/5th linear scale LPG tanks. Out of the five tests reported, four were equipped with various designs of internal protection systems using Explosafe. These systems were used to protect or at least delay the rupture of tanks under fire accident conditions. The fifth test (ENIGMA) was performed without an Explosafe filling. The fire was made in each test using JP-4 fuel. Data on the fire environment, the average heat fluxes around the vessels, the operation of the pressure relief valve and the mass flow rate through the valve for each reported test, were obtained. These tests also provided wall, vapour and liquid temperature distributions and fire temperatures around each vessel.

Roberts, Cutler and Billings [4] conducted a series of fire engulfment tests on 500 litre LPG tanks. The tanks contained 200 litres of liquid and were installed above a pool of kerosene oil surrounded by a 1 m high windshield. The flames from the burning kerosene totally engulfed the tank. Tests were conducted with uninsulated and a variety of insulated tanks containing propane. In each trial, data were obtained on heat transfer rates to the vapour and liquid, as well as tank wall temperatures.

In their tests, the PRV first operated after three minutes for the uninsulated tank and in the range of 12-90 minutes for the insulated tanks. It was often thought that the liquid propane boiled in the film boiling regime since high wall temperatures below the apparent liquid level were observed. With the insulation systems boiling was observed to be in the nucleate region since low wall temperatures in the liquid region were noted.

1.2.2 Geysering Systems

Only two studies regarding geysering systems were found, one by Griffith [5] and the other by Anderson [6].

Geysering in vertical, liquid filled lines was studied by Griffith [5]. The purpose of this work was to evaluate the mechanisms of geysering, measure the maximum heat flux that could be tolerated without geysering and determine the geysering frequency. Testing was conducted on lines ranging in inside diameter from 0.437 to 1.875 inches with lengths from 20.25 to 61.0 inches. Water, methanol and Freon-11 were used as the test fluids. The experimental results indicated that whenever geysering occurred, it was accompanied by a transition to slug-flow in the line. An attempt was made to define criteria for the maximum heat transfer rate that could be tolerated in the transfer line without geysering.

Anderson [6] studied the geysering phenomenon both experimentally and analytically. The purpose of this study was to develop an analytical method by which the occurrence of geysering in the transfer line could be predicted. The experimental part of this study utilised various lengths of transfer lines of 4 and 6 inch diameter with water and liquid nitrogen as test fluids. Trials were conducted on transfer lines at orientation angles of 0°, 30° and 60° from the vertical. During testing with water, heating was accomplished by variable power electric heater blankets strapped to the externally insulated transfer lines. Since liquid nitrogen boils at very low heating rates, heat addition in this case was controlled by adding various layers of external insulation.

The experimental results defined geysering heat flux limits for various transfer line configurations. In the analytical part, a calculation technique for predicting geysering occurrence was developed by Anderson [6] which used a correlation for flooding [12] in vertical lines. Anderson tested this empirical relation using different fluids and the work of Griffith [5] and found excellent agreement between the prediction and experimental values.

CHAPTER 2

EXPERIMENTAL FACILITY

In the present study, a horizontal cylinder test section was used to experimentally simulate the thermal behaviour of rail tank cars and their lading when engulfed by fire. The design of the experimental apparatus provided for the visualisation of the flow and measurements of temperatures and pressures, with a variety of different fills, PRV orifice sizes and heat fluxes.

The fire boundary condition was simulated by an electrical heat flux condition due to the relative ease of assembly, control and measurement. Refrigerant R-11 (Freon-11) was used as the experimental working fluid as it condenses at atmospheric pressure and hence boils at moderate temperature and pressure.

Details regarding the construction of the complete test section and the auxiliary equipment are described in the following sections.

2.1 The Test Section

Figures 2.1(a) to 2.1(c) are photographs of the experimental system and instrumentation and the complete experimental facility is shown schematically in Fig. 2.1(d). The test section consists of the following components:

1) a horizontal cylinder comprised of a heater inner and a cold outer shell complete with thick plexiglass windows at each end;
2) a solenoid operated pressure relief valve with a variety of orifice sizes;
3) nine electrical heaters strapped directly to the outside wall of the inner shell;
4) an electronic weighing system for measuring the mass discharged through the PRV, connected to an LSI-11 computer and data acquisition system (Fig. 2.1(b); and
5) a HP-85 mini computer along with a HP-3497A data acquisition/recording unit, for thermocouple scanning and pressure monitoring and PRV control (Fig. 2.1(c)).

2.1.1 The Horizontal Cylinder

The horizontal cylinder consists of inner and outer shells of inside diameters of 381 mm and 470 mm, respectively. They are made of 304 stainless steel and mild steel with the wall thickness of 6.4 mm and 8 mm respectively. The inner shell can withstand internal pressures up to 1720 KN/m^2. The main purpose of designing the cylinder with inner and outer shells, was to permit placement of the electrical heaters around the outer wall of the inner shell within the outer shell. An argon gas atmosphere was provided between the two shells at a pressure slightly above the R-11 test pressure so to minimise the high thermal hoop stresses on the inner shell and also to minimise the heat losses from the heaters.

For flow visualisation, both ends of the cylinder were fitted with removable 25.4 mm thick plexiglass end plates held in position by a reinforced end closure. Silicone rubber "O"-rings were used to provide the seal between the plexiglass end plates and the ends of the inner and outer shells.

2.1.2 The Heating System

Heat was provided to the test section by three sets of three electrical heaters. Each heater consisted of a six coil element. Each coil (305 mm long and 9.5 mm diameter) was made of 16 gauge Kanthal A1 wire having a resistance of 12 ohms. The coils were placed in circular slots in a Lava block as shown in Fig. 2.2(a). Three phase 208 V power was supplied to the heaters. The control circuit is shown in Fig. 2.2(b). Each set of three heaters was wired in a delta formation and the manual power adjustment made using the variac and a current meter. A watt-meter was connected between variac 1 and the first set of heaters. Variac 1 was first adjusted to one-third of the desired power and then the balance was fed to the other two sets of heaters using variacs 2 and 3 connected to the heaters 4 to 9. Matching was made with the help of a clamp type current meter. Power remained nearly consant throughout an experimental run since resistance change of approximately one percent occured at the operating temperature of the heater (approximately 500-600°C).

2.1.3 Weighing System for Mass Flow Measurements

This system consisted of four capacitor type weighing balances (Range 300 lbs, excitation voltage for single reading 1.5 volts and 3.0 volts for multiple readings) which were used to measure the mass and mass flow rate of fluid through the PRV. These scales were connected to four channels of an LSI-11 computer which measured the frequency from the scales and which was later converted to mass flow rate units and input manually after each experimental run into the data acquisition system.

2.1.4 Thermocouple Assembly

Thermocouples were fixed to the inside walls of the inner and outer shells and also placed at various locations in the interior of the inner shell. These were connected to 42 channels of the HP-3497A data logger and digital voltmeter, which in turn was linked to the HP-85 computer. Those thermocouples attached to the inside wall of the inner shell and located in the liquid and vapour spaces were led out through the rear plexiglass end plate through four connector assemblies as shown in Fig. 2.3(a). Three of these connectors carried 24 thermocouples and the fourth one carried 12 thermocouples. Vapour and liquid temperature profiles in the inner shell were obtained using class I type copper constantan thermocouples, whereas temperatures of Lava and inside walls of inner and outer shells were measured with class I type iron-constantan thermocouples.

The measurements of all thermocouples were recorded as functions of time. Each being identified by its respective channel number and its spatial position (vertical or circumferential) in the inner as well as outer shell of the cylinder. The spatial positions of the thermocouples used for obtaining vapour-liquid stratification, were obtained with a cathodemeter. An example of the layout of thermocouples is shown in Fig. 2.3(b). The specific detailed layout for each reported run is given in Appendix III.

2.1.5 Pressure Transducer

A Data Instruments Model AB pressure transducer (Range 500 psig, overload 2 times rated pressure, excitation voltage of 6 volts maximum and sensitivity of 20 mV/volt) was used to measure the pressure variation inside the inner shell of the horizontal cylinder. This transducer was connected to one channel of the HP-3497A data acquisition/recording unit, controlled by the HP-85 computer. The DC voltage was measured from the channel and converted to pressure using the calibration curve provided to manufacturer's stated accuracy of ± 1 percent.

2.1.6 Video-recording Unit

This unit comprised of a Sony video camera (VC #116), a Sony VCR (type SLO-323) and a colour television. The system was used for recording tests. The video-camera had a built-in timer for recording the start, stop and elapsed time for a test to an accuracy of 2/100 seconds. The video cassette recorder (VCR) had a capability of playing back the picture and sound of a recorded video cassette on a regular TV receiver in slow, regular or fast speeds. Slow motion viewing of every test could be used for detailed analysis of the thermo-hydraulic phenomena occurring in liquid and vapour spaces as functions of time.

2.1.7 Expected Accuracy of Measurements

For the temperature measurement, voltage (DC) from thermocouple junctions are measured using the HP-3497A data acquisition/recording units. The HP-85 computer converts these voltages to temperatures using a cubic spline method with an accuracy of $\pm 0.1^{\circ}C$. For the pressure measurement a calibration curve for the pressure transducer is made. The DC voltage is measured from the HP-3497A for a known pressure and plot against each other. The best linear curve is fitted which gives a precision of ± 0.1 psig for the pressure measurements.

In order to measure the mass flow rate through the

PRV using the four weighing balances, each scale was calibrated separately. For each balance, frequencies from the channel of the LSI-11 computer were read for corresponding applied loads. These applied loads ranged from 0 to 135 lbs. The loads were removed from the scales to verify the reproducibility and repeatability. These frequencies were plotted against applied loads and the best linear curve was fitted. Each individual curve for the four balances was used to determine the mass and the mass flow rate. The mass was estimated to be accurate to ± 0.5 lbs.

2.2 Design of the Pressure Relief Valve

The main components of the pressure relief valve (PRV) designed for the present study, are the converging nozzle, the valve and its stem, the valve seat, the disc, the housing and the spring. An assembled valve is shown in Fig. 2.4. The PRV was used with and without a spring in this study. Some of its characteristics are as follows:

(1) Set pressure: the pressure at the valve inlet at which it is going to lift, set in the computer program prior to the experiment and controlled by the instrumentation system.

(2) Over pressure: is the predetermined pressure increase above the set pressure at which the discharge capacity of the valve is attained. This is usually

expressed as a percentage of the set pressure. For this study, full lift was set to occur at a pressure of 103% of set pressure [1].

(3) Lift: the ~~act~~ual distance the valve disc moves away from the valve seat.

(4) Reseat pressure: the pressure at the valve inlet at which the valve disc re-establishes contact with the seat or at which the lift becomes zero. This pressure should not be lower than 95% of the set pressure [1]. This pressure was also set prior to an experimental run and controlled by the data acquisition system.

(a) Assumptions

In this study the PRV was designed using similar assumptions to those adopted by Sallet [7], namely:

(i) the valve is located in the vapour space of the horizontal cylinder;

(ii) if violent boiling does not occur in the tank, only saturated or superheated vapour will flow through the valve, otherwise isentropic homogeneous two-phase fluid flow may occur; and

(iii) the valve discharge coefficient for vapour as well as for the high quality two-phase mixture is assumed to be constant and to have a value of 0.9.

(b) Vapour only flow

When a closed horizontal cylinder which contains a volatile liquid is subjected to a heat input, this causes a rise in temperature and a corresponding increase in pressure.

The rate of vapour generation inside the cylinder with heat addition is:

$$\dot{\bar{m}} = \frac{\dot{Q}}{\Delta h_o} \tag{2.1}$$

where

$\dot{Q} \equiv$ kW $\equiv$ the total heat input per unit time into the cylinder;

$\dot{\bar{m}} \equiv$ kg/sec $\equiv$ rate of vapour generation; and

$\Delta h_o \equiv$ kJ/kg $\equiv$ latent heat of vaporisation.

The mass of fluid which is vented so to prevent an increase in pressure varies depending upon the location of the PRV. If the valve is located in the vapour space, the only possible discharge regimes can be choked vapour or two phase flow. The required mass flow rate of vapour in order to prevent pressure buildup is given by [8]:

$$\dot{m}_v = \dot{\bar{m}}(1 - \frac{V_L}{V_g}) \tag{2.2}$$

where V_L and V_g are specific volumes of liquid and vapour respectively.

The valve sizing equation relates the minimum area A_v^* of the relief valve to the mass flow rate m_v which in turn is related to the heat input [8]:

$$\dot{m}_V = C_d\, G_v\, A_v^* \tag{2.3}$$

where

C_d ≡ valve discharge coefficient determined usually by experiments; and

G_v ≡ mass flux for the flow of a dry or superheated vapour corresponding to choked condition (kg/m^2-sec).

Choked vapour flow occurs as long as the ratio of vessel pressure to atmospheric pressure is greater than critical [7]:

$$\frac{P_o}{P_{atm}} \geq \left(\frac{2}{K+1}\right)^{\frac{K}{1-K}} \tag{2.4}$$

where $K = C_p/C_v$.

The mass flux G_v for vapour is therefore [9],

$$G_v = \frac{P_o}{\sqrt{\frac{ZRT_o}{gM}}} \sqrt{K\left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}} \tag{2.5}$$

where

M ≡ molecular weight of test fluid;

Z ≡ compressibility factor; and

"o" ≡ stagnation condition in the cylinder.

The minimum area A_v of the relief valve is therefore

$$A_v = \frac{\dot{m}_v}{C_d\, G_v} = \frac{\dot{Q}(1 - \frac{V_L}{V_g})}{h_o\, C_d\, G_v} \qquad (2.6)$$

In the present study, three PRV nozzles were selected for heat fluxes to the liquid of 10, 25 and 50 kW/m^2 corresponding to 9.5, 16 and 25.4 mm throat diameters.

2.3 The Test Program and Experimental Procedures

A summary of the test program is given in Table 2.1. The work was conducted in two phases, one without and the other with Explosafe. Explosafe is an expanded aluminum foil mesh used for reducing the vapour space wall temperature rise to reach the critical value at which the material strength starts to deteriorate. In the present study, 25.4 mm thick Explosafe (Style III) was used.

In all cases before loading the inner shell with R-11, argon gas was supplied to the cavity between inner and outer shells of the horizontal cylinder. This cavity was pressurised to a pressure greater than that anticipated for the PRV set pressure in order to balance pressure on the heated vessel and to provide an inert gas atmosphere to the heaters. With the heater cavity pressurised, the PRV was opened and liquid R-11 was loaded through a bottom filling valve. The PRV orifice was open to avoid pressure buildup and the trapping of any non-condensable gases in the inner shell.

After filling the inner shell to the desired level, the LSI-11 weighing system was set to measure the mass and the mass flow rate. Then the HP-85 computer and data acquisition/recording system were set and the heater power turned on along with the video recording system. The flow diagram for the temperature and pressure scanning program and its listing is given in Appendix I.

The data acquisition system scanned all thermocouples and monitored pressure as a function of time. The data were stored in the computer memory and processed and reduced values displayed on its CRT screen. Data scans without conversion to temperature or pressure took five seconds for 42 readings. Conversion to temperatures and pressure normally took 28 to 30 seconds per scan. Scans without venting were therefore conducted at approximately 30 second intervals.

When the vessel pressure reached the PRV set pressure, the control program caused the PRV to open. The HP-85 system in addition, generated a signal to the LSI-11 which scanned its four channels to measure the frequency from the scales as a function of time which were later converted to the mass flow rate.

If the valve remained open, the computer continued to scan all thermocouples and displayed on its printer only the converted vessel pressure as a function of time after every scan. In this mode, each scan took 7 to 8 seconds. The microvolts measured from the junctions of thermocouples were converted to temperatures after completion of the test.

Tests performed with and without Explosafe were videorecorded for reference and later detailed analysis. Data in terms of temperatures and pressure as a function of time, were stored on computer discs and are listed in Appendix III along with the detailed layout of thermocouple locations for each test.

CHAPTER 3

EXPERIMENTAL RESULTS

In this chapter wall and vapour temperature profiles in the vapour space of the partially filled tank are presented.

3.1 Wall and Vapour Temperature Profiles in the Vapour Space of the Unprotected Tank

Vapour space circumferential wall temperatures as functions of time for the two PRV orifices and three liquid levels tested, are shown in Figs. 3.1 and 3.2. The electrical heater input was 65 kW/m^2 in all cases. In general, it may be observed that wall temperatures near the vapour-liquid interface are less than wall temperatures near the top of the vessel, and also the circumferential vapour space wall temperatures are non-uniform. In the vapour space, there is an unheated portion (i.e. no heaters placed in 6 or 7^o at the top most region of the vessel) of the wall around the pressure relief valve.

Vertical vapour and liquid space temperature profiles for the same two PRV orifices and the three liquid levels tested are presented in Figs. 3.3 to 3.8. These temperatures are plotted as a function of the vessel height and will now be individually discussed in some detail.

3.1.1 76% Liquid Fill

For a very short duration of time after the sudden application of power to the outer circumference of the inner shell, the heat transferred into the vapour space may be expected to be by conduction only. From Fig. 3.3, it may be observed that vapour and liquid temperature profiles are almost vertical up to the scan number 3 (78.3 seconds). This can be interpreted to mean that the vapour is stagnant (i.e., no circulation) and hence conduction prevails during this time period. Due to the low density and viscosity of vapour and its large thermal expansion coefficient and since a large temperature gradient exists in the fluid adjacent to the wall, free convection in vapour results.

Fig. 3.3 also shows that in less than two minutes (scan #4), there is considerable convection of vapour. Convection sets in much more rapidly in the vapour rather than in the liquid as may be observed from the temperature-height plot (Figs. 3.3 to 3.8). This is to be expected since the buoyancy forces for the vapour are much greater than for the liquid and the resistance to motion from inertial and viscous forces is smaller. A very small temperature gradient at the wall is therefore sufficient to set the fluid in motion.

Condensation of vapour at the topmost unheated section of the tank occurs, when the vapour heated by the hot wall moves along the unheated surface and loses its energy. This may be observed from the bulges in vapour temperature profiles in Fig. 3.3. Further condensation results as the vapour is compressed by the expansion of the liquid.

In Fig. 3.3 the vapour temperature increases with height until the PRV opens (i.e., the vapour is hottest at the top of the tank and coolest at the vapour-liquid interface). This stable stratification of vapour results naturally due to the heating process. The vapour flow that results during heating, rises above the colder vapour as a buoyant flow and a recirculating flow is established. The vertical density variation due to the vertical temperature gradient however, reduces the free convection effect as time progresses. This decreases the heat removal from the heated vapour space wall; the wall temperatures therefore increase continuously until the PRV opens. Fig. 3.1 may illustrate these phenomena.

When the PRV opens, initially only superheated vapour flows through the PRV. The mixing effect of vapour and liquid due to forced convection reduces wall and vapour temperatures during the discharge (Figs. 3.1 and 3.3).

As soon as the PRV closes, the wall and vapour temperatures recover almost immediately and stratification continues.

After the first three PRV vents, wall and vapour temperatures are not significantly affected by the PRV cycling except for the vapour temperature near the liquid-vapour interface (Fig. 3.3).

3.1.2 58% Liquid Fill

After the sudden application of a constant heat flux to the tank, the vapour remains stagnant up to almost one minute (scan #3) with only conduction heat transfer to the vapour (Fig. 3.4). Soon after, free convection of vapour results along with recirculation. Condensation also results on the unheated portion of the vapour space. The vertical temperature variation caused by the upward movement of heated vapour adjacent to the wall results in stable stratification of vapour. The stratification becomes more severe as the vertical vapour temperature variation is increased with time and reduces the free convection effect on the vapour space wall faster than the 76% liquid fill case. This results in an increase of the rate of change of wall temperatures as compared to the 76% fill (Figs. 3.1 and 3.4). Stratification continues to become more pronounced as time progresses until the PRV opens.

When the PRV opens, wall and vapour temperatures are not affected very much as only superheated vapour appears to flow through the PRV (Fig. 3.4). The wall and vapour temperatures are less affected compared to the higher level fill.

Fig. 3.4 shows that as soon as the PRV is closed, vapour temperatures recover immediately and stratification becomes more pronounced. This decreases further the free convection effect in the vapour space and wall temperatures increase continuously with time. Comparing the two liquid fillings, the vapour space wall temperatures are higher compared to wall temperatures obtained with the 76% liquid fill.

3.1.3 23% Liquid Fill

In this case, free convection starts almost immediately in the vapour space after the application of the heat flux (Fig. 3.5). Stratification of vapour commences and increases more rapidly than in the other two fills reducing the free convection effect in the vapour space. The rate of increase of wall temperatures is higher than the other two liquid fills. Stratification is more pronounced in 23% fill, with condensation of vapour starting earlier and continuing until the PRV opens as compared to the higher fill levels.

When the PRV opens, wall and vapour temperatures are affected less than with the higher liquid fillings. Forced convection due to PRV cycling causes less mixing of liquid and vapour. This may be observed from the vertical vapour temperature profile in Fig. 3.5. Even though the PRV cycles, wall and vapour temperatures continuously increase with time as shown in Figs. 3.1 and

3.5, respectively.

3.1.4 Effect of the Valve Orifice Area on Wall and Vapour Temperature Profiles

Two pressure relief valve (PRV) orifices (6.4 mm (1/4") ϕ and 9.5 mm (3/8") ϕ) were employed to examine their effects on mass discharge, vapour stratification, wall and vapour temperatures and the two phase swelling.

Fig. 3.2 shows wall temperatures with the larger size orifice while the stratification plots for this orifice with three liquid fills are presented in Figs. 3.6 to 3.8. From the wall and vapour temperature profiles, it is observed that they change considerably when the PRV is open. Due to the PRV opening, the tank pressure drops and the liquid volume is increased. Fluid motion caused by this change in the tank pressure, results in the mixing of liquid and vapour. A high quality two phase frothing (bubbly flow) due to flashing, causes liquid swelling, that is an increase in liquid level, due to the entrained vapour. In this case, the two phase swelling caused by the PRV opening, is 4.0, 2.7 and 1.8 cm for 76, 58 and 23 percent liquid fills, respectively. Forced convection predominates in the vapour space and decreases wall and vapour temperatures due possibly to the evaporation of liquid droplets entrained in the flow (Figs. 3.2 and 3.6). The variation of vapour temperature profile in the vertical direction becomes small due to the thorough mixing caused by this forced convection; vapour stratification therefore decreases. With 76% and 58% liquid fills, wall and vapour temperatures reduce to close saturation values with the larger size orifice. In the 23% liquid fill case, however, it can be seen that the wall and vapour temperatures do not change significantly (Figs. 3.2 and 3.8) as was the case for the same fill for the smaller orifice.

When the PRV with the smaller orifice is open, two phase swelling is 1.45, 1.34 and 1.2 cm, respectively. With this orifice, superheated vapour initially flows through the PRV and the vertical temperature profile is affected only up to the two phase swelling level. Forced convection effects also cause less mixing with this orifice since there is a greater resistance to flow which results in less discharge. The wall and vapour temperatures, however, do not change as greatly during PRV cycling which is evident from Figs. 3.1 and 3.3 to 3.5.

Further, a comparison is made by plotting the wall and vapour-liquid temperature profiles for the two PRV orifices in Fig. 3.9, to observe their effects on the temperature profiles during PRV cycling. From this figure, one can see that the wall and vapour temperatures in the vapour space with the 3/8" PRV orifice, are significantly lower than those with the 1/4" PRV orifice.

3.2 Wall and Vapour Temperature Profiles in the Vapour Space of the Explosafe Equipped Tank

Explosafe, an expanded aluminum foil mesh as shown in Fig. 4.1, is used to prevent or at least delay the rupture of an LPG-carrying tank car in case of fire engulfment during accidents. Explosafe is inserted inside the tank to transfer heat away from vapour covered regions of the tank vapour space wall and enhance the heat transfer in the vapour space.

Three tests were performed with an Explosafe equipped vessel for liquid levels of 74, 58 and 23 percent, respectively. The PRV orifice diameter was 3/8" in. with a heat flux of 40 kW/m^2.

The vapour space circumferential wall temperatures for three liquid levels are shown in Fig. 3.10. From this figure, it can be seen that wall temperatures increase continuously with time until the PRV opens. When the PRV opens, wall temperatures do not decrease considerably. From Fig. 3.10, it may be observed that the temperature gradient in the tank wall in the axial direction is negligible, which means the axial conduction heat transfer in the vapour space wall is also negligible.

The vertical temperature distributions in vapour-liquid spaces for three liquid levels are shown in Figs. 3.11 to 3.13.

3.2.1 76% Liquid Fill

The initial heat transfer to the vapour is by conduction (Fig. 3.11). After approximately two minutes, sufficient temperature gradients exist in the vapour space wall to set the vapour into motion and convection commences. From Fig. 3.11, it is obvious that the vapour temperature near the vapour-liquid interface is larger than the vapour temperature at the top of the tank. This vertical temperature variation with the vessel height results in stable vapour stratification. This stratification tends to inhibit mixing which in turn, reduces the convection effect at the wall in the vapour space as time progresses. The wall temperatures therefore, increase continuously (Fig. 3.10).

When heated vapour moves upward along the tank wall it loses its energy and condensation of vapour occurs in the unheated region of the vapour space. The initial liquid level also increases because of thermal expansion of liquid and generation of vapour in the liquid space. This increase in the liquid level results in compression of vapour.

From the vertical temperature profiles before the first vent (Fig. 3.11), the vapour temperature at the top of the tank is smaller than the vapour temperature near the interface. It appears from these temperature profiles that heat is transferred from the vapour to the wall.

Comparing temperatures of wall and vapour (Figs. 3.10 and 3.11), however, it is obvious that heat is transferred to the vapour.

When the PRV opens for the first time, a fluid motion caused by changes in tank pressure results in some lateral mixing of the vapour and liquid and a high quality two phase frothing occurs in the tank. It was expected that the liquid and vapour would be well-mixed due to a circumferentially layered Explosafe mesh but this did not occur. The wall and vapour temperatures are not significantly changed during the PRV cycling except the vapour temperature near the interface as shown in Fig. 3.11. After two or three vents (scan #24), a very low quality two phase mixture or superheated vapour seems to flow through the PRV and may be observed in Fig. 3.11. Forced convection takes place during each discharge through the PRV.

When the PRV is closed, wall and vapour temperatures recover almost immediately (Fig. 3.11) and free convection comes into the picture again in the vapour space. Vapour stratification becomes more pronounced with time and reduces the convection effect continuously.

3.2.2 58% Liquid Fill

When the constant electrical power input is applied, the mode of heat transfer to the vapour is by conduction. Convection starts in the vapour space earlier than with 76% fill level (Figs. 3.11 and 3.12). Stable vapour stratification, due to the vertical temperature gradient, reduces the convection effect at the vapour space wall. This reduction is faster compared with the higher fill level. The wall temperatures therefore increase continuously as shown in Fig. 3.10. The rate of change of wall temperatures is higher than in the higher liquid fill.

Condensation of vapour also occurs with this liquid level until the PRV is open. When the PRV opens, wall and vapour temperatures are affected less as compared with the higher liquid level. Only superheated vapour appears to flow through the PRV during the discharge (Fig. 3.12).

The wall and vapour temperatures recover almost immediately after the PRV is closed (Figs. 3.10 and 3.12). Stratification of vapour continues to reduce the convection effect at the vapour space wall.

3.2.3 23% Liquid Fill

From Fig. 3.13, it may be observed that convection currents start in the vapour space soon after the heaters are turned on. Heated vapour adjacent to the wall, moves upward along the curved wall and is diverted into the vapour space by the strands of Explosafe. This results in good mixing of vapour in the vapour space. The vertical temperature curves from 6 to 9 in Fig. 3.13, illustrate this effect. After five minutes, a stable vapour stratification occurs due to the vertical temperature variation which reduces the convection effect in the vapour space of the Explosafe equipped tank. The rate of change of wall temperatures is therefore, increased. The wall temperatures are highest with 23% liquid fill as compared to the higher levels of liquid fill. Condensation of vapour also occurs in the unheated region of the vapour space.

When the PRV opens for the first time, superheated vapour only flows through the PRV. Forced convection due to the PRV opening, does not affect vapour and wall temperatures and they continue to increase (curves 15 to 17, Figs. 3.13 and 3.10). Stratification increases with time and is more severe in the 23% fill.

CHAPTER 4

HEAT TRANSFER MODELS AND CORRELATION

A simple theoretical model was developed to attempt to explain the heat transfer processes in the vapour space. This model attempts to portray the fluid behaviour and its associated heat transfer for the UNB tank, the full-scale [2] and the one-fifth scale [3] tanks, respectively. The model is applicable to tanks equipped with and without Explosafe.

4.1 General Model for the Heat Transfer in the Vapour Space of a Tank With and Without Explosafe

The problem investigated was the transient heating of vapour in a partially filled horizontal cylinder with and without Explosafe, with heat input applied circumferentially. The following assumptions were made (Fig. 4.2):

1) The wall of the vessel is thin, so that the temperature on the inside and outside surface of the vapour space wall is the same (calculations in Appendix III.3.6 verify that the temperature gradient across the wall is small).

2) The heat stored in the vapour space wall is large due to the thermal capacity and density of the steel shell.

3) The internal radiation from the vapour space wall to the liquid surface in an unprotected tank is negligible except at high vapour space wall temperatures (Appendix III.3.2).

4) The internal heat radiation in the Explosafe equipped tank is negligible due to the low emissivity of polished stainless steel and aluminum foil (Appendix III.3.3).

5) External radiation to the surroundings may take place due to the high emissivity of the surface under heated conditions (Lava emissivity, $\varepsilon_{LA} = 0.9$ and steel emissivity, $\varepsilon_s = 0.7$ [11]).

6) The heat stored in Lava blocks cannot be neglected due to the high thermal capacity and density of the Lava.

7) Circumferential conduction in the tank wall from the vapour space to the liquid space at the interface may be neglected except when the tank volume occupied by liquid is quite large (e.g. 90%) and vapour space wall temperatures are high.

4.1.1 The UNB Tank

Based on the assumptions made, the model to determine the vapour space heat transfer is shown in Fig. 4.2. An energy balance may be written as:

$$Q_{IN} = Q_{RELS} + Q_{LA} + Q_{ST} + Q_{CONV} + Q_{COND} \qquad (4.1)$$

Q_{COND} is neglected by assumption (7), so the net energy balance is given by:

$$Q_{IN} = Q_{RELS} + Q_{LA} + Q_{ST} + Q_{CONV} \tag{4.2}$$

and a detailed energy balance in the vapour space of the UNB tank is [11]:

$$Q_{IN} = \frac{\sigma(T_{LA}^4 - T_{SS}^4)}{\frac{1-\varepsilon_{LA}}{\varepsilon_{LA}} + \frac{1}{F_{LA-SS}} + \frac{1-\varepsilon_{SS}}{\varepsilon_{SS}}(\frac{A_{LA}}{A_{SS}})} + \rho_{LA} C_{pLA} t_{LA} \frac{TLAV^{(n+1)} - TLAV^{(1)}}{(\tau^{(n+1)} - \tau^{(1)})}$$

$$+ \rho_s C_{p_s} t_s \frac{(TWVAV^{(n+1)} - TWVAV^{(1)})}{(\tau^{(n+1)} - \tau^{(1)})} + h^{(n)}(TWVAV^{(n)} - T_V^{(n)}) \tag{4.3}$$

Hence the heat transfer coefficients may be calculated using the experimental data given in Appendix III since

$$h^{(n)} = [Q_{IN} - \frac{\sigma(T_{LA}^4 - T_{SS}^4)}{\frac{1-\varepsilon_{LA}}{\varepsilon_{LA}} + \frac{1}{F_{LA-SS}} + \frac{1-\varepsilon_{SS}}{\varepsilon_{SS}}(\frac{A_{LA}}{A_{SS}})}$$

$$- \rho_{LA} C_{p_{LA}} t_{LA} \frac{(TLAV^{(n+1)} - TLAV^{(1)})}{(\tau^{(n+1)} - \tau^{(1)})}$$

$$- \rho_s C_{p_s} t_s \frac{(TWVAV^{(n+1)} - TWVAV^{(1)})}{(\tau^{(n+1)} - \tau^{(1)})}] / (TWVAV^{(n)} - T_V^{(n)}) \tag{4.4}$$

The magnitude of each individual term in equation (4.4) is dependent on constant material properties and the temperature distribution as a function of time. For 65 kW/m^2, the heat stored in the steel shell and in the Lava blocks, varies from 9-13% and 55-60%, respectively while the external radiation from the Lava blocks to the outer steel shell ranges from 8-10%. The convective heat transfer, therefore, varies accordingly.

4.1.2 Full and One-Fifth Scale Tanks

In order to determine the heat transfer coefficient in the vapour space in the case of unprotected vessels engulfed with fire [2, 3], the energy balance given by (4.1) can be restated as follows (Fig. 4.3):

$$Q_{IN} = Q_{RE} + Q_{RI} + Q_{ST} + Q_{CONV} \tag{4.5}$$

A detailed derivation is given in Appendix III.2. The energy balance yields:

$$Q_{IN} = \sigma\varepsilon_s T_W^4 + \frac{\sigma(T_W^4 - T_L^4)}{\frac{1-\varepsilon_W}{\varepsilon_W} + \frac{1}{F_{W-L}} + \frac{1-\varepsilon_L}{\varepsilon_L}(\frac{A_W}{A_L})}$$

$$+ \rho_s C_{p_s} t_s \frac{(T_W^{(n+1)} - T_W^{(1)})}{(\tau^{(n+1)} - \tau^{(1)})} + h^{(n)}(T_W^{(n)} - T_V^{(n)}) \tag{4.6}$$

The heat transfer coefficient may be calculated at any time level using the following expression:

$$h^{(n)} = [Q_{IN} - \sigma\varepsilon_s T_W^4 - \frac{\sigma(T_W^4 - T_L^4)}{\frac{1-\varepsilon_W}{\varepsilon_W} + \frac{1}{F_{W-L}} + \frac{1-\varepsilon_L}{\varepsilon_L}(\frac{A_W}{A_L})}$$

$$- \rho_s C_{p_s} t_s \frac{(T_W^{(n+1)} - T_W^{(1)})}{(\tau^{(n+1)} - \tau^{(1)})}]/(T_W^{(n)} - T_V^{(n)}) \qquad (4.7)$$

The magnitudes of external and internal radiation vary from 0-25% and 0-20% respectively while the heat stored in the shell varies from 30 to 50%. The convective heat transfer is, in turn, dependent on these terms and heat input to the vapour space.

4.1.3 One-Fifth Scale Tank (NOVA)

When the vessel is equipped with Explosafe and engulfed with fire [3], the heat transfer model is shown in Fig. 4.4 and the energy balance given by equation (4.5) becomes:

$$Q_{IN} = Q_{RE} + Q_{ST} + Q_{COND} \qquad (4.8)$$

A detailed energy balance in the Explosafe equipped vessel NOVA [3] is:

$$Q_{IN} = \sigma\varepsilon_s T_W^4 + \rho_s C_{p_s} t_s \frac{(T_W^{(n+1)} - T_W^{(1)})}{(\tau^{(n+1)} - \tau^{(1)})} + h^{(n)}(T_W^{(n)} - T_V^{(n)}) \qquad (4.9)$$

Therefore the heat transfer coefficient 'h' may be determined using the following expression:

$$h^{(n)} = \left[Q_{IN} - \sigma\varepsilon_s T_W^4 - \rho_s C_{p_s} t_s \frac{(T_W^{(n+1)} - T_W^{(1)})}{(\tau^{(n+1)} - \tau^{(1)})}\right] / (T_W^{(n)} - T_V^{(n)}) \qquad (4.10)$$

4.2 Model for the Heat Transfer in the Vapour Space of the UNB Tank Using An Alternate Method

In order to model in an alternate manner the convective heat transfer in the vapour space, the electric heater coil is modelled. The following assumptions are made:

1) Heat is transferred from the heater wire to both the Lava and the vapour space wall by radiation (Appendix III.3.5).

2) Conduction heat transfer in the gas region is negligible due to very low thermal conductivity of argon gas (Appendix III.3.5).

3) The thermal capacity of the heater element is neglected due to the low density and specific heat of the wire.

On the basis of these assumptions, the heat transfer model based on the shaded control volume, is shown in Fig. 4.5 and an energy balance on the heater wire is given as follows:

$$Q_{IN} = Q_{RLA} + Q_{CONDG} + Q_{RS}$$

$$Q_{IN} = \sigma(T^4_{WIRE} - T^4_{LA}) + K_g \frac{(T_{WIRE} - T_g)}{dr_g} + \sigma(T^4_{WIRE} - T^4_W) \tag{4.11}$$

A detailed analysis is made in Appendix III.1 and only the final equation valid for argon is given here:

$$0 = 1.1338\text{ E-07 } T^4_{WIRE} + 0.99\ T_{WIRE} - (5.669\text{ E-08 } (T^4_{LA} + T^4_W) + 0.496\ (T_{LA} + T_W) + Q_{IN}) \tag{4.12}$$

The wire temperature (T_{WIRE}) has been evaluated for the unprotected vessel with a heat flux of 65 kW/m^2, a PRV orifice of 1/4" diameter and 76% liquid full. These wire temperatures are plotted in Fig. 4.6 and the values are given in Table 4.1. From Fig. 4.6, it may be observed that the wire temperature reaches the asymptote value in only 10 seconds.

The heat radiation from the heater wire to the outer surface of the inner shell (Q_{RS}) is the heat input to the vapour space. Therefore, an energy balance on an element of the wall in the vapour space, shown in Fig. 4.5, may be stated as:

$$Q_{RS} = Q_{ST} + Q_{COND} + Q_{CONV} + Q_{RI}.$$

The radiation heat exchange between the vapour space wall and the liquid surface (Q_{RI}) is negligible (Appendix III.3.2). Therefore, the convective heat transfer in the vapour space may be given as:

$$Q_{CONV} = Q_{RS} - (Q_{ST} + Q_{COND}) \qquad (4.13)$$

Sample calculations for one test are shown in Appendix III.3.5.

4.3 Analysis of the Vapour Space Heat Transfer Results

Heat transfer coefficients in the vapour space of partially filled tanks with and without Explosafe, were evaluated using the experimental models discussed in section 4.1.

4.3.1 Unprotected Tanks

Vapour space heat transfer results for the unprotected UNB tank are presented in Figs. 4.7 to 4.9. These results are presented for heat fluxes ranging from 10 to 65 kW/m^2 and two PRV orifices of 1/4" and 3/8" diameters. The sample calculations are given in Appendix III.3.

From Figs. 4.7 to 4.9, it may be observed that vapour space convective heat transfer coefficients start decreasing soon after the electric heaters are turned on. A continuous decrease in free convection of vapour is caused by stable vapour stratification. This stratification is due to the density gradient caused by the vapour temperature variation in the upward vertical direction. Therefore, a decrease in free convection effect of vapour at the vapour space wall reduces the heat transfer to the vapour space. The experimental results shown in Figs. 3.1 to 3.8 also illustrate this phenomena.

When the PRV opens convective heat transfer coefficients increase due to forced convection and when the valve is closed the heat transfer coefficients decrease which may be observed from Figs. 4.7 to 4.9.

The vapour space heat transfer coefficient in the UNB tank appears to be high. Therefore the heater coil wire is modelled to obtain convective heat transfer coefficients at any time level for verification. From Fig. 4.6 and sample calculations (Appendix III.3.5), it may be observed that circumferential conduction in the tank wall from the vapour space to the liquid space, also plays an important role in the vapour heat transfer only when vapour space wall temperatures are high and the volume occupied by the liquid.is large. Convective heat transfer coefficients evaluated from the heat transfer model are therefore found to be 5 to 12% high, which is true only for 76% liquid fill, 1/4" diameter orifice and 65 kW/m^2 case.

For the validity of heat transfer results, a comparison is also made between the lower bound values of convective heat transfer evaluated from a conduction heat transfer model. for 76% liquid fill, 1/4" ϕ orifice and 65 kW/m^2 heat flux, convective heat transfer coefficient evaluated at 298 seconds are compared

(Appendices III.3.1 and III.3.3). The lower bound value of 'h' is 0.5 W/m^2-^{o}C while 'h' determined from the model is 298 W/m^2-^{o}C. From this comparison, one can anticipate that the heat transfer coefficient evaluated using the model will be higher compared to the lower bound value.

Heat transfer results in the vapour space of the full-scale tank [2] and the one-fifth scale tank, ENIGMA [3], are shown in Fig. 4.9. Sample calculations are given in Appendix III.3.3.

The modes of heat transfer in the full-scale tank are similar to the UNB tank, however, there are some major differences. In the full-scale tank, external radiation from the heated shell to the surrounding and internal radiation from the vapour space wall to the liquid surface, plays an important role in the vapour space heat transfer. However, internal radiation in the UNB tank is negligible due to very low emissivity of polished stainless steel inner shell and lower vapour space wall temperatures. Stable vapour stratification is therefore more pronounced in the UNB tank as compared to vapour stratification in the full-scale tank.

In the case of the one-fifth scale tank ENIGMA [3], the heat transfer modes were similar to those of the full-scale tank, however, vapour stratification is much more pronounced similar to the UNB tank. This may be observed by comparing Fig. 4.11 with Figs. 3.3 to 3.8.

4.3.2 Explosafe Equipped Tanks

In order to demonstrate the capability of Explosafe as a heat transfer enhancement device, several experiments were performed by inserting 25.4 mm thick Explosafe (Style III) in the UNB tank. Results of vapour space heat transfer in the UNB tank and the one-fifth scale tank, NOVA [3] are presented in Fig. 4.10. Results of only three tests with 40 kW/m^2 in the UNB tank are presented. Sample calculations are given in Appendix III.3.3.

From Figure 4.10, it may be observed that the heat transfer coefficient decreases very sharply soon after heat is supplied to the vapour space. Convection heat transfer continuously decreases due to increase in a stable vapour stratification caused by the vertical density gradient. The vapour heat transfer decreases consistently until the PRV opens.

When the PRV opens for the 74% liquid fill, the heat transfer coefficient continues to decrease. Wall and vapour temperatures are not affected due to less effective forced convection. After venting a couple of times, the convective heat transfer coefficient increases due to more effective forced convection which is caused by a thorough mixing of vapour and liquid in the vapour space. Wall and vapour temperatures are therefore reduced (Figs. 3.9 to 3.12).

With lower liquid fills (58% and 23%) the heat transfer coefficient in the vapour space decreases even during the valve cycles. The heat transfer in the vapour space is certainly better with 76% fill than the other two liquid levels which may be observed from Fig. 4.10.

The modes of heat transfer in the vapour space of the one-fifth scale tank (NOVA) are similar to those of the Explosafe equipped UNB tank. From the temperature distributions reported for NOVA [3], it is observed that temperature gradients at the wall are less severe compared to the unprotected tank, ENIGMA [3]. From the radial temperature profile with 60% liquid fill as shown in Fig. 4.11 [3], it is seen that the vapour temperature profile beyond the outer layer of the Explosafe has similar characteristics to ENIGMA. This shows that convection is the main heat transfer mode in the vapour space and radial conduction is negligible in the circumferential layered system of the Style III Explosafe used. This may be observed from the vertical temperature profile for NOVA as shown in Fig. 4.11.

4.4 Correlation Development

In order to test the models developed the experimental vapour heat transfer results prior to venting for the UNB tank, full-scale and one-fifth scale tanks with and without Explosafe, were correlated. The heat transfer in the vapour space is free convection in the UNB tank whereas in full-scale and one-fifth scale·tanks, the modes of heat transfer are free convection and radiation. Internal radiation in Explosafe equipped tanks is however negligible.

In order to develop the correlation, the experimental data in terms of the heat transfer coefficient and temperature difference between the wall and vapour were plotted against each other as shown in Figs. 4.7 to 4.10. The trend of the plots shows that convective heat transfer decreases with time and reaches an asymptote value at large times.

A correlation was first sought in which all the experimental data for each run could be included. The various forms of correlation which were attempted are[14]:

$$Nu = C(Ra)^n \tag{4.14}$$

$$Nu = C(Ra \cdot Fo)^n \tag{4.15}$$

$$Nu = C(Ra \cdot Fo)^n \cdot Ra^m \tag{4.16}$$

$$Nu = C(N_{COND})^n \tag{4.17}$$

$$Nu = C(Fo)^n \tag{4.18}$$

In all cases, correlations were made using a least square method. Relations (4.14) to (4.17) did not fit the data.

Since conduction is the mode of heat transfer through the tank wall with heating rate as the time dependent variable, only one dimensionless number can accommodate this, the Fourier number. A correlation was therefore, sought between the Nusselt and tank Fourier number.

The best correlation for the heat transfer to the vapour space was found to be:

$$Nu = 817579\ (Fo)^{-1.4932} \qquad (4.19)$$

with

$$Nu = \frac{hL_c}{k_v} \quad \text{and} \quad Fo = \frac{k_s \tau}{\rho_s C_{p_s} t_s^2}$$

where the characteristic length L_c was based on the volume of vapour and the heated area in the vapour space, i.e. $L_c = V_v/A_h$. This correlation fitted all the data for the vapour heat transfer of the UNB tank, full and one-fifth scale tanks with and without Explosafe as shown in Figs. 4.12 to 4.14. A correlation coefficient of 0.92 and a maximum deviation of ± 25% was obtained.

From the Fig. 4.12, it is obvious that the heat transfer data for the Explosafe equipped vessels are shifted to the right-hand side of the curve which means heat transfer was enhanced in Explosafe equipped tanks. Therefore, a separate correlation was sought for the heat transfer data with Explosafe. The best empirical relation for the heat transfer data with Explosafe was:

$$Nu = 1247762 * (Fo)^{-1.575} \qquad (4.20)$$

This fitted the data with a correlation coefficient of 0.94.

In spite of the moderate success in correlating the experimental data as a function of time, there remain a number of questions regarding the validity of this correlation. First, does a single dimensionless group representation in fact exist. Even though the present problem has a very strong time dependence, the present correlations are based entirely on the properties of the steel shell through which the conduction heat transfer takes place throughout the test, since the Fourier number is directly proportional to time and inversely proportional to the properties of the steel wall. Therefore, if the starting time is changed or the vessel is already heated before an experimental run, it would be impossible to correlate the data with the present correlation.

The second question arises from the characteristic length used in the Nusselt number calculations. In the present empirical relation, this length is calculated for four different liquid levels in the vessel and averaged over time. The vapour volumes and heated areas are however dependent on the liquid levels in the vessel. When the PRV cycles, these regions increase and decrease. In the present correlation, this has not been taken into account.

Further, this relation has only been tested for different heat fluxes ranging from 10 kW/m^2 to 110 kW/m^2

and with diameters of vessels ranging from 0.381 to 3.048 meters and it has been used to correlate the heat transfer results for different liquid levels. The correlation has also employed two working fluids, propane and Freon-11.

CHAPTER 5

ALTERNATE PROTECTION METHODS

5.1 Description of the Problem

In order to protect or at least delay the rupture of a tank by reducing the vapour space wall temperature and pressure before they reach critical values, an alternate protection scheme known as geysering was proposed.

Geysering in vertical or non-vertical fluid transfer lines is the rapid expulsion of liquid from the line as a result of vapour generation within the line at a rate in excess of that which could be released by normal bubble buoyancy.

Three conditions contribute to the formation of a geyser. They are:

(i) high external heating of the line;
(ii) little or no forced circulation within the line; and
(iii) thermodynamic saturation of the liquid in the line.

Depending on the severity of the geyser, the expelled liquid can be propelled to significant heights above the liquid free surface in reservoirs, i.e., in the vapour space. In the case of vessels or large tank cars with a restricted gas volume above the liquid surface and limited vent area, the expulsion of liquid into the gas region can produce rapid and significant cooling of the vapour space wall as well as the vapour with subsequent reduction in the tank pressures.

One of the problems in analysing geysering processes is the necessity to distinguish between geysering and non-geysering conditions. A strong or violent geyser can be easily distinguished but a weak geyser is difficult to distinguish from a rapid boiling condition that can occur in a heated line. A geyser can be identified not only by a visual observation of the liquid expulsion from the top of a transfer line, but also by the significant reduction in the pressure at the bottom of the line. The pressure reduction occurs because of the sudden decrease in fluid density in the line as well as the bulk of the fluid when the liquid is expelled. Also, the sudden decrease in the temperature indicates that the line has refilled with the cooler fluid from the vessel.

A non-geysering condition has been defined as one in which the system temperature stabilization is achieved with no visible evidence of liquid expulsion from the transfer system. This condition is characterized by there being no significant pressure changes occurring in the bulk for some time after fluid temperatures are stabilized.

5.2 Purpose of This Work

The main objectives of this study were to:

(i) study the possibility of enhancement of the heat transfer in the vapour space of a partially filled tank using the geysering process as an alternate interior protection system; and

(ii) model the geyser and non-geyser situations for determining the vapour space wall temperatures and design the possible geyser systems for the UNB and the full-scale LPG tanks.

5.3 Geyser Prediction Model and Correlation

In evaluating the geysering process in the fluid transfer lines, Anderson [6] made the following assumptions:

(1) The boiling process generates sufficient turbulence in the line.

(2) The vapour velocity leaving the line is equal to the bubble rise velocity occurring in the slug flow regime.

(3) The total heat transfer rate into the transfer line is equal to the product of the applied heat flux and the line surface area.

(4) The total heat entering the line is absorbed by the vaporization of the liquid.

(5) Before a geyser occurs in the transfer line, the liquid mass flow entering the line is equal to the vapour flow leaving so that a constant mass is maintained

in the line which means liquid flow will be equal to the vapour mass flow rate, i.e., $m_g = m_L$.

On the basis of these assumptions, the relation for predicting the occurrence of a geyser in a fluid transfer system based upon flooding theory, was developed by [6] and is given by:

$$\left(\frac{q}{h_{fg}K_\theta}\right)\left[\frac{1}{gD(\rho_f-\rho_g)}\right]^{\frac{1}{2}}\left[\left(\frac{1}{\rho_g}\right)^{\frac{1}{2}}+\left(\frac{1}{\rho_f}\right)^{\frac{1}{2}}\right]^2 = C_0\left(\frac{L}{D}\right)^{-2.201} \quad (5.1)$$

where $C_0 = C^2/4$ and C is given as:

$$C = \left(\frac{4q}{h_{fg}K_\theta}\right)^{\frac{1}{2}}\left(\frac{L}{D}\right)^{\frac{1}{2}}\left\{\left[\frac{1}{gD(\rho_f-\rho_g)}\right]^{\frac{1}{2}}\left[\left(\frac{1}{\rho_g}\right)^{\frac{1}{2}}+\left(\frac{1}{\rho_f}\right)^{\frac{1}{2}}\right]\right\} \quad (5.2)$$

Eqn. (5.1) is the desired relation for predicting the occurrence of a geyser in vertical and non-vertical lines, where the L.H.S. is known as geysering index (N_G). It can be applied in the following manner. For a given transfer line, geometry, fluid and applied heat flux, both sides of the equation are calculated. If the geysering index (N_G) is greater or equal to the R.H.S., geysering would occur. In other words, eqn. (5.1) defines the separation line above which geysering occurs and the region below, which is a non-geysering region.

A correlation was also developed by Anderson [6] to correlate the experimental data for different fluids and heat fluxes to predict the geyser and non-geyser situations for vertical and non-vertical lines. This relation is written as follows:

$$N_G \cdot N_{Jm}^{0.803} = 5.769\ (L/D)^{-2.201} \qquad (5.3)$$

where N_{Jm} is the modified Jakob number and is given by

$$N_{Jm} = \frac{\rho_f C_{p_f} T_{sat}}{\rho_g h_{fg}}$$

The fluid properties used in these equations must be the saturation values evaluated from the fluid pressure. K_θ in eqn. (5.1) is a dimensionless factor given by Wallis [12] to modify the vertical bubble rise velocity for transfer lines inclined at an angle θ from the vertical.

5.4 Optimization of the Diameter and the Critical Heat Flux

Based on the previous expressions and assumptions, the following assumptions were made for evaluating the geysering in tanks (Figs. 5.4 and 5.5):

(1) Heat flux on the transfer line is based on the heat absorbed by the fluid in the vessel.

(2) Length is constant but diameter varies for the optimization of the diameter.

(3) The number of lines are selected for the system on the basis of heat and amount of cooling produced by one line on a certain wall area of the cylinder.

(4) The properties ρ_f, ρ_g, h_{fg} and C_{p_f} are evaluated

at the pressure inside the vessel when geysering occurs.

Based on these assumptions, as made by Anderson [6], geysering was predicted in the UNB and a full-scale tank for the working fluids Freon-11 and propane respectively. Figs. 5.1 and 5.2 show the plots for the geyser indices and length-to-diameter ratios. These plots present the separation line both for geyser and non-geyser situations.

The heat flux was maintained constant and the $N_G(N_{Jm})^{0.803}$ product was calculated for five different L/D ratios. The heat flux was then increased and the product of geyser index and the modified Jakob number for the same L/D ratios were again calculated. These were plotted against each other as shown in Figs. 5.1 and 5.2. It is observed that L/D ratios of 21.70 and 38.5 are most suitable for geysers for the UNB and a full-scale tank respectively. Therefore, 16 mm and 10.2 cm are the optimum diameters for transfer lengths of 0.343 m and 2.9 m necessary for the UNB and a full-scale tank respectively.

5.5 Heat Transfer Models for Geyser and Non-Geyser Situations

In order to determine whether the geysering process can enhance the heat transfer in the vapour space and reduce the temperatures of the wall and vapour, geysering and non-geysering situations have been modelled.

5.5.1 Without Geysering

The following assumptions were made:

(1) the heat transfer coefficient h_g is constant on the inside surface;

(2) the wall heat flux q_v is constant; and

(3) the wall temperature, T_W is a function of time.

The model is shown in Fig. 5.3(a). Applying the first law of thermodynamics, a lumped formulation of the problem is:

$$\rho_s C_{p_s} t_s \frac{dT_w}{d\tau} = q_v - h_g(T_w(\tau) - T_g) \tag{5.4}$$

with the initial condition

$$T_w(0) = T_{w_i}$$

Therefore the heat input to the vapour space, q_v, is

$$q_v = \rho_s C_{p_s} t_s \frac{dT_w}{d\tau} + h_g(T_w(\tau) - T_g)$$

Letting $A = \rho_s C_{p_s} t_s$ and $\beta = h_g T_g$ and integrating with time, τ, we obtain:

$$\tau = \frac{-A}{h_g} \ln(q_v + \beta - h_g T_w(\tau)) + C \tag{5.5}$$

Substituting the initial condition and solving for C, we have

$$C = \frac{A}{h_g} \ln(q_v + \beta - h_g T_{w_i}) \tag{5.6}$$

Substituting the value of C in eqn. (5.5), we obtain

$$\tau = \frac{A}{h_g} \ln[\frac{(q_v + \beta - h_g T_{w_i})}{(q_v + \beta - h_g T_w(\tau))}]$$

or

$$\frac{h_g \tau}{A} = \ln[\frac{q_v + \beta - h_g T_{w_i}}{q_v + \beta - h_g T_w(\tau)}]$$

$$e^{h_g \tau / A} = \frac{q_v + \beta - h_g T_{w_i}}{q_v + \beta - h_g T_w(\tau)}$$

Solving for $T_w(\tau)$, we have

$$T_w(\tau) - T_{w_i} e^{-h_g \tau / \rho_s C_{p_s} t_s} = (\frac{q_v + h_g T_g}{h_g})(1 - e^{-h_g \tau / \rho_s C_{p_s} t_s}) \qquad (5.7)$$

which is the required relation for the heat transfer without a geyser.

5.5.2 Geysering Situation

The model is shown in Fig. 5.3(b). An energy balance is now

$$q_v = \rho_s C_{p_s} t_s \frac{dT_w}{d\tau} + h_g(T_w(\tau) - T_g) + q_f$$

where q_f = heat extracted from the vapour space wall by the geysering process. Here $q_f = \alpha_f * m_f * h_{fg}$ where α_f is the percentage of the fluid which hits the vapour space wall and evaporates. Therefore

$$(q_v - q_f) = \rho_s C_{p_s} t_s \frac{dT_w}{d\tau} + h_g(T_w(\tau) - T_g) \qquad (5.8)$$

with the same initial condition $T_w(0) = T_{w_i}$ as before. Solving this equation in the same manner as for non-geyser situation, the following result is obtained:

$$T_w(\tau) - T_{w_i} e^{-h_g \tau / \rho_s C_{p_s} t_s} = \frac{(q_v - q_f + h_g T_g)}{h_g} (1 - e^{-h_g \tau / \rho_s C_{p_s} t_s}) \qquad (5.9)$$

Comparing the two situations, the vapour space wall temperatures will decrease with geysering relative to the situation without a geyser. It is however difficult to predict the amount of cooling produced due to the geyser because cooling is dependent on the heat extracted by the expelled liquid during geysering and is hence dependent on the mass flow rate of liquid and the fraction of the liquid which evaporates α_f

$$q_f = \alpha_f m_f h_{fg}$$

The factor, α_f, will be dependent on the velocity and the intensity of the geyser as well as the mass flow rate of the propelled liquid and hence is best determined empirically.

5.6 System Designs for Geysers

Two geyser systems are proposed here to protect the vessel's vapour space wall from overheating. They are shown in Figs. 5.4 ~~and~~-5.5. As far as the author is concerned, system (I) seems to be more practical because as the liquid in the cavity is heated by the high heat flux, the vapour generation rate increases and the pressure in the inner vessel will also increase. It will try to force the liquid down through the slots or holes into the cavity as shown in Fig. 5.4. In the fluid transfer system, liquid boiling produced by a uniform heating can be tolerated up to a certain rate. At or below this time, the vapour generated by boiling and rising due to buoyancy can be replaced by the liquid flow down the inner vessel. The flow pattern under this condition would be counter-current. During this counter-current flow, shear stresses developed between the liquid and vapour phases would tend to retard the liquid downflow. Anderson [6] has however, described these retarding forces as small and the counter-current condition to be stable.

As the heat flux increases further, the boiling rate will increase. The system will, therefore, become unstable and in this case, the interface shear stresses would rise rapidly and impede the downward flow of the liquid. Further increase in the vapour generation rate will result in a reversal of the liquid downflow. This would cause the expulsion of the liquid circumferentially in the cavity. The expelled liquid would cool the vapour space by evaporation.

System II has a similar operation as observed by the fluid transfer line system described earlier.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A series of experiments involving partially filled R-11 horizontal tanks equipped with and without Explosafe has been conducted to determine in part the vapour space heat transfer.

Two pressure relief valve (PRV) orifices of 6.4 mm ϕ and 9.5 mm ϕ and three liquid levels of 76, 58 and 23 percent were employed to perform six experiments in an unprotected vessel. The heat flux in all cases was 65 kW/m^2. Three tests were also performed with an Explosafe equipped vessel filled with liquid levels of 74, 58 and 23 percent and a PRV orifice of 9.5 mm ϕ. The heat flux for these tests was 40 kW/m^2.

In tanks equipped with and without Explosafe, the mode of heat transfer in the vapour space is primarily by free convection which eventually stagnates due to stratification. Internal radiation from the vapour space wall to the liquid surface plays a significant part in the vapour space heat transfer only if wall temperatures are large. Circumferential conduction in the tank wall from the vapour space to the liquid space at the interface may play an important role in the vapour space heat transfer especially with large fills. When the valve opens, forced convection of the vapour governs tank wall temperatures, however, the intensity of this convection is dependent upon PRV size.

The heat transfer results have revealed that the vapour space heat transfer based upon the temperature difference between the wall and vapour, decreases until the PRV opens. Once open the PRV enhances vapour space heat transfer.

The two PRV orifices used have shown significant effects on wall and vapour temperature profiles for the unprotected vessel. Results reveal that forced convection predominates in the vapour space and causes a considerable reduction in wall and vapour temperatures when the larger PRV is used. With 23% liquid filling, the PRV cycling with both orifices, has little effect on wall and vapour temperatures. When the PRV is closed, vapour stratification is more severe.

Explosafe was employed as an internal protection system to enhance the vapour space heat transfer in a series of tests performed at 40 kW/m^2. Results showed that free convection was the mode of heat transfer in the vapour space and vapour stratification was also less severe than with unprotected tanks. Wall and vapour temperatures were not affected as severely during PRV cycling as with the unprotected tanks.

An empirical relation was developed to correlate the experimental data of vapour space heat transfer with and without Explosafe. The relation correlated the data of the full-scale, the one-fifth scale and the UNB tank equipped with and without Explosafe quite well with a correlating coefficient of 0.92 and a maximum deviation of ± 25%. In general the Nusselt number obtained decreased with time to an asymptotic value as the Fourier number increased.

Geysering has been proposed to enhance the vapour space heat transfer. Heat transfer models have been developed for cases with and without geysering. Two geyser systems are proposed.

6.2 Recommendations

1) The estimate of the vapour space heat transfer based on electrical power measurements is very sensitive to heat losses. Therefore, the only possible choice for an estimation of the vapour space heat transfer is that based on the integrated average of the temperature measurements in the vapour space. The heat flux Q_v is defined by the expression:

$$Q_v = \frac{d}{d\tau} \left(\int_0^{T_v} \rho_v \, L_c \, C_{p_v} \, dT \right)$$

It can be approximated by

$$Q_v = \rho_v \, L_c \, C_{p_v} \frac{dT_v}{d\tau}$$

and the heat transfer coefficient 'h' can be evaluated using the following relation:

$$h = \frac{Q_v}{(T_w - T_v)}$$

This method is recommended to improve the estimate of the heat transfer in the vapour space.

2) The present heaters in the UNB vessel should be replaced by strap heaters to obtain even heat flux distribution on the outer surface of the inner shell vapour space wall.

3) The instrumentation of the UNB vessel should be upgraded to obtain the accurate and precise estimation of the vapour heat transfer. First, the circumferential temperature distribution on inside and outside surfaces of the inner shell vapour space wall should be obtained. This distribution will help in the evaluation of more exact heat storage and the circumferential conduction terms in the tank wall.

Second the temperature of the heater wire and circumferential and radial temperature distributions of Lava blocks in the vapour space should be obtained. From the heater wire temperature, an exact estimation of heat radiation from the heater coil wire to the outer surface of the inner shell vapour space wall, will be obtained. While the circumferential and radial temperature distributions of Lava blocks will give a better estimation of heat storage in the Lava and circumferential and radial conduction in the Lava. With these modifications, the accuracy of vapour heat transfer will improve.

4) The liquid level in the UNB tank should be monitored. In some circumstances when the valve opens, the tank completely fills with a two phase mixture. It is difficult to determine the vapour space volume and heated area under these circumstances. Capacitor void fraction gauges are recommended in the vertical diameter of the UNB tank, for monitoring this parameter as a function of time. This will increase the accuracy in determining the vapour space heat transfer.

5) A series of tests should be attempted with the geyser systems I or II inside the inner shell to observe the effect on the wall and vapour temperature profiles in the vapour space. Further, the equations of heat transfer with and without geyser should be verified.

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FIGURES

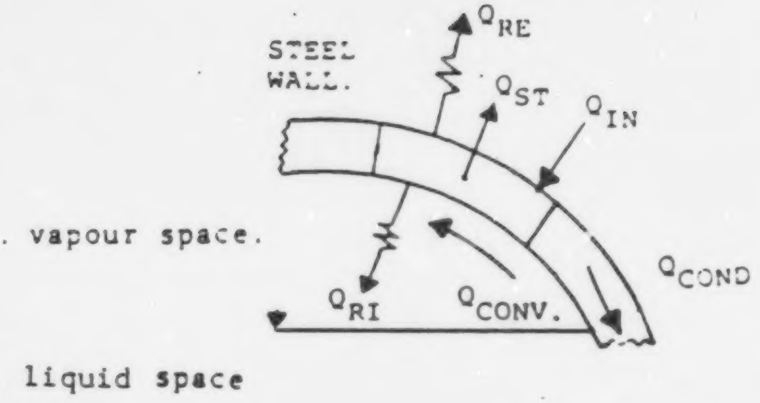
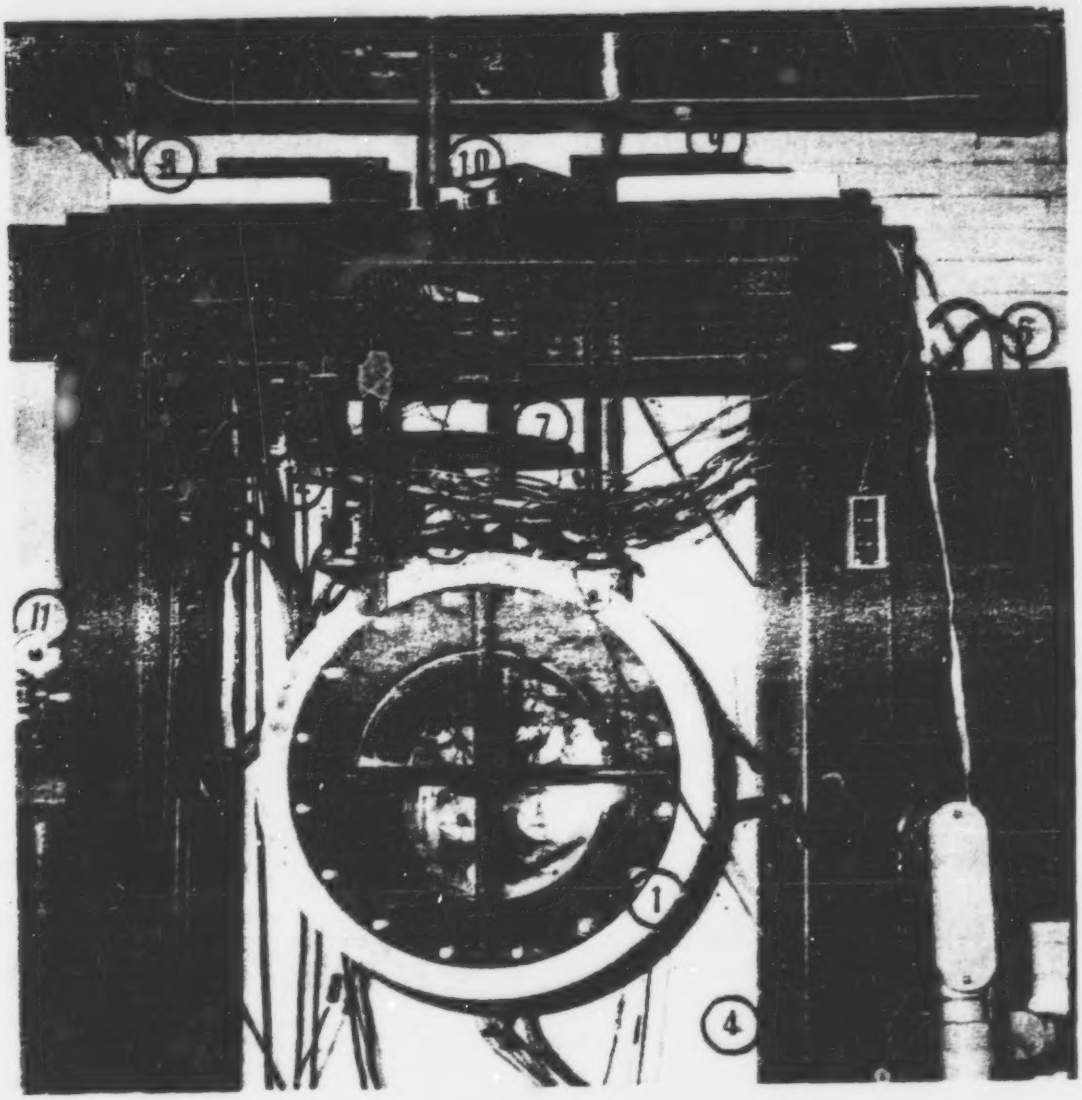
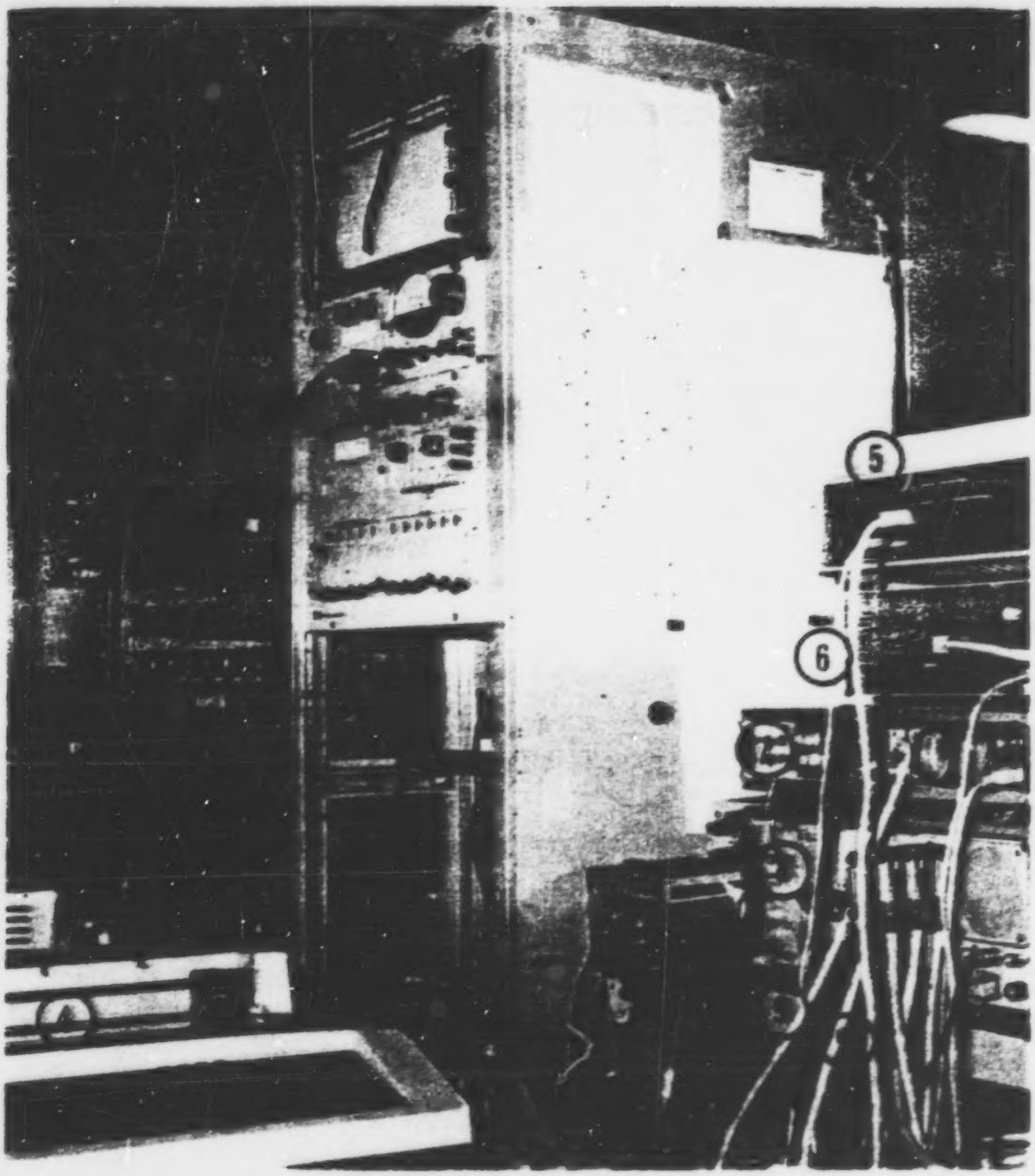


Fig. 1.1 Energy balance on an upper element of the tank wall in the vapour space.



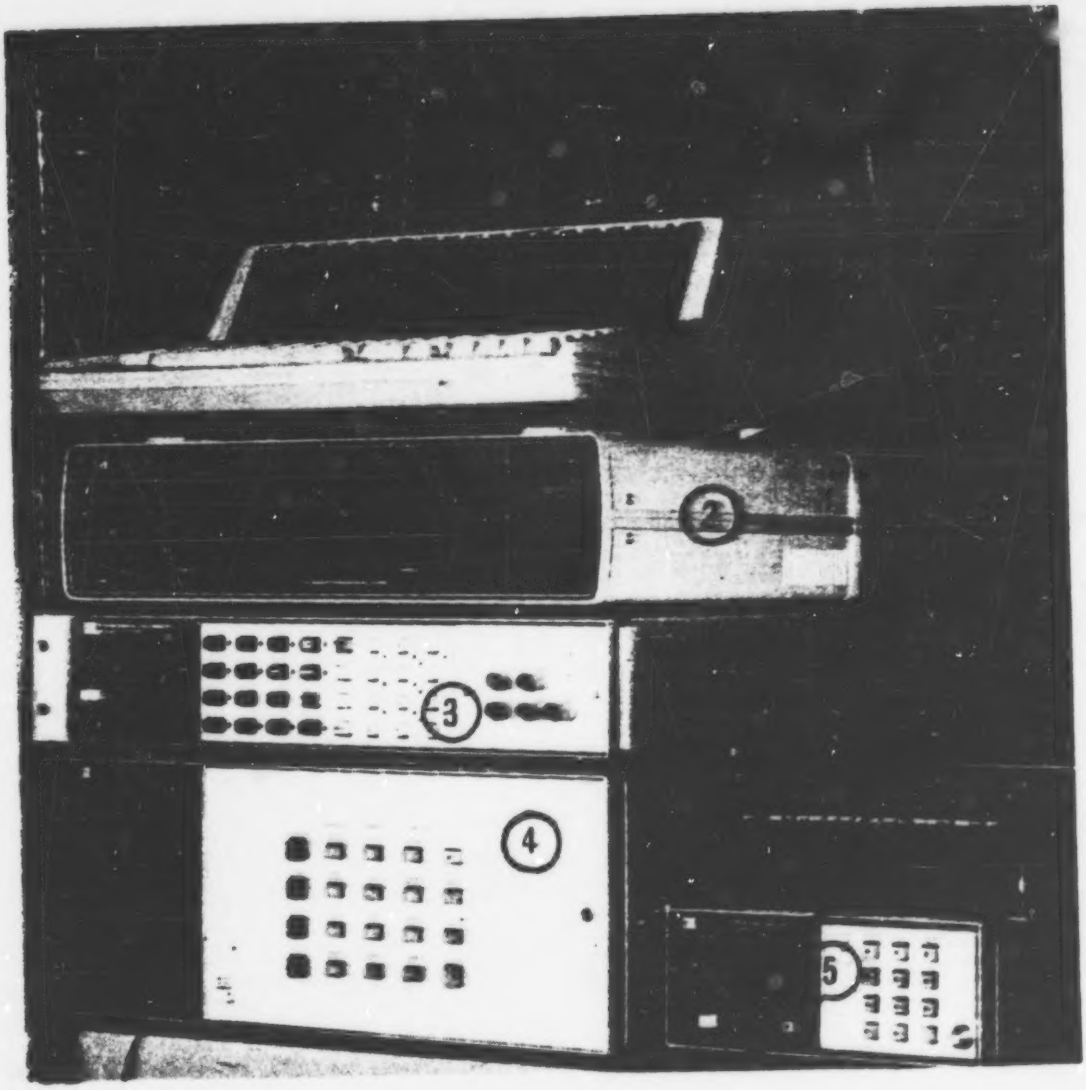
1: Test Section with inner and outer vessels;
2: Thermocouples Rig; 3: PRV discharge port;
4: Steel structure; 5: Pressure transducer;
6: Electrical control panel; 7: Thrust plate;
8: Weighing balances; 9: Steel lugs with flat surfaces to hang the vessel on balances;
10: Power supply for balances; 11: Argon gas cylinder; 12: Solenoid assembly for opening and closing of PRV; 13: Cooling system.

Fig. 2.1(a) Complete experimental setup.



1: LSI-11 computer; 2: Channels of LSI-11;
3: Digital voltmeter; 4: Input/output printer;
5: Rear view of HP-85 mini-computer;
6: Rear view of Disc drive; 7: Rear view of HP-3456A digital voltmeter: 8: Rear view of HP-3497A data acquisition/ Control unit;
9: Thermocouple leads connected to HP-3497A.

Fig. 2.1(b) LSI-11 computer with the data acquisition and recording system.



1: HP-85 mini-computer; 2: Disc drive;
3: HP-3456A digital voltmeter;
4: HP-3497A Data acquisition/Control unit;
5: HP-3437A digital voltmeter;
6: Power supply for pressure transducer.

Fig. 2.1(c) Computer with complete data acquisition system.

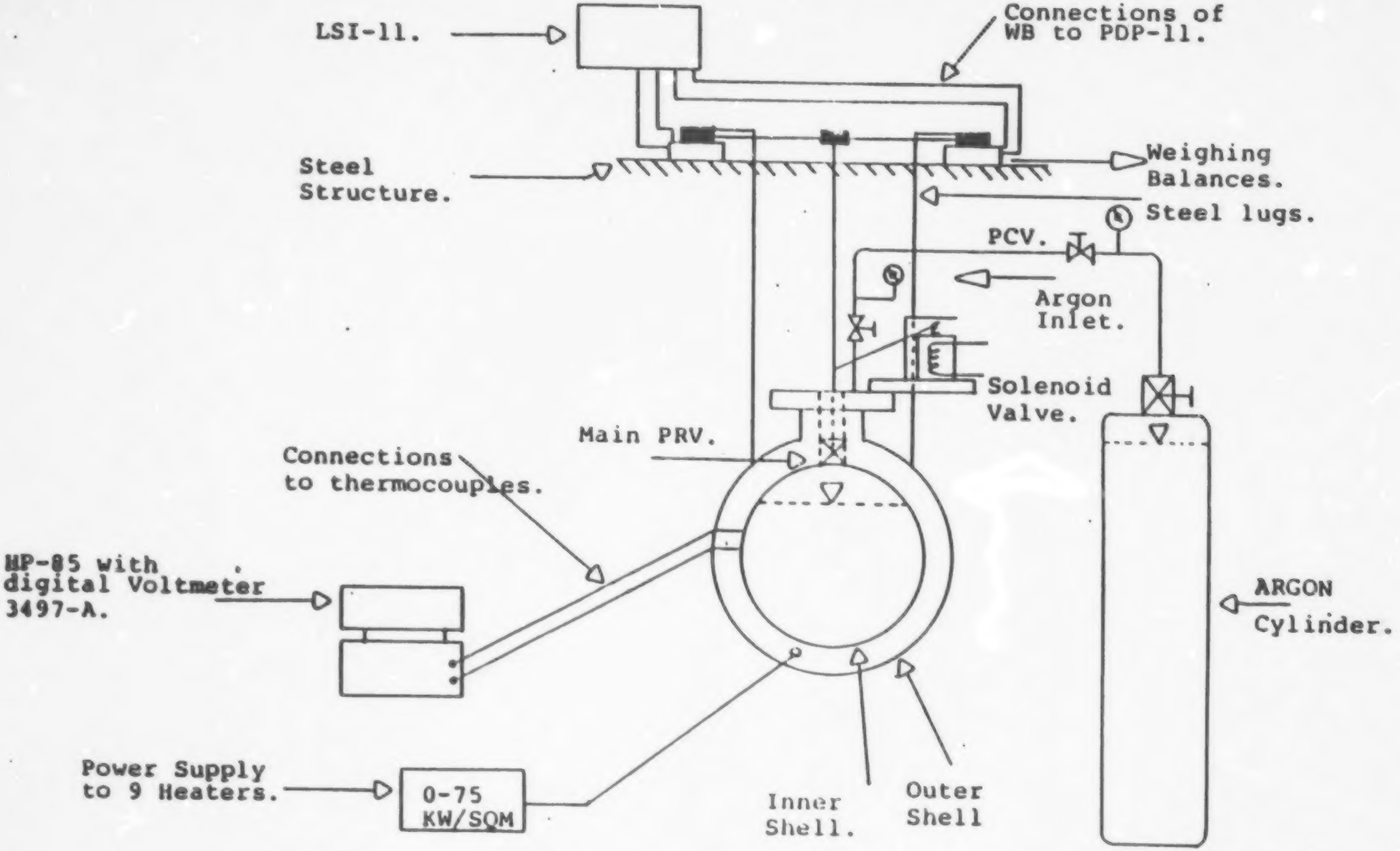


Fig. 2.1(d) Schematic diagram of the experimental setup.

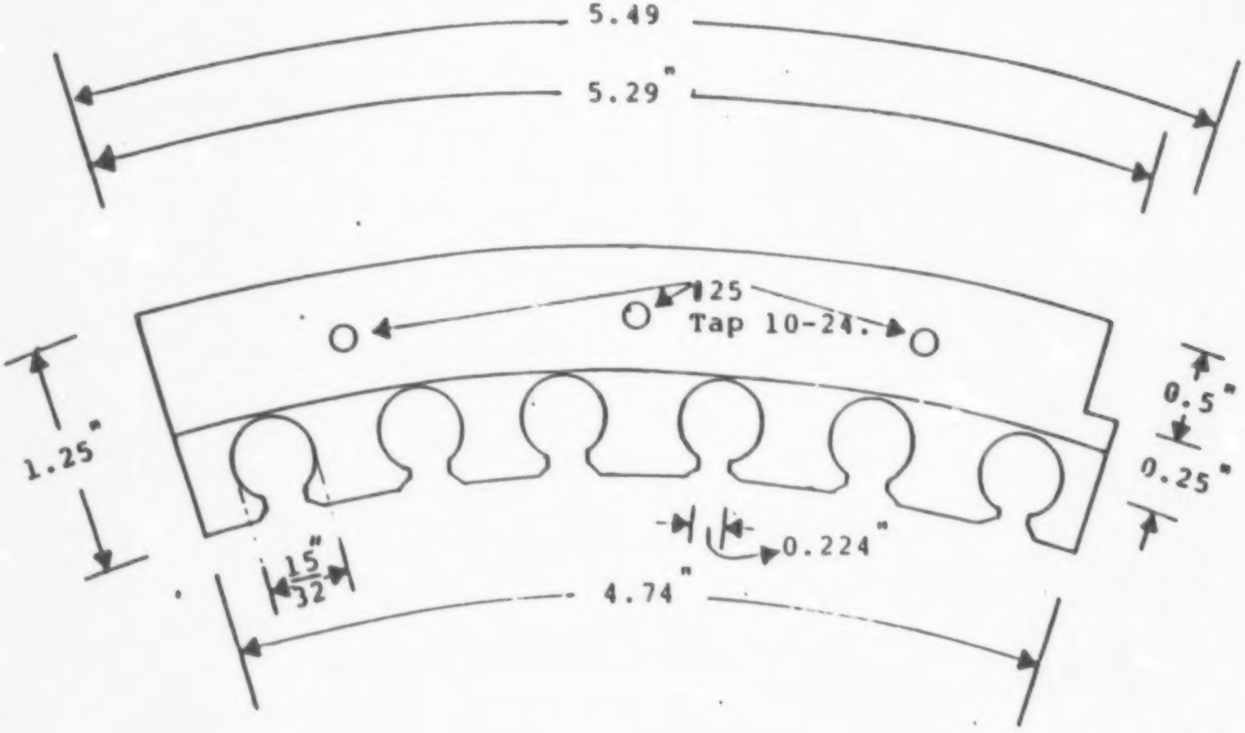


Fig. 2.2(a) End view of the Lava housing for electrical heaters.

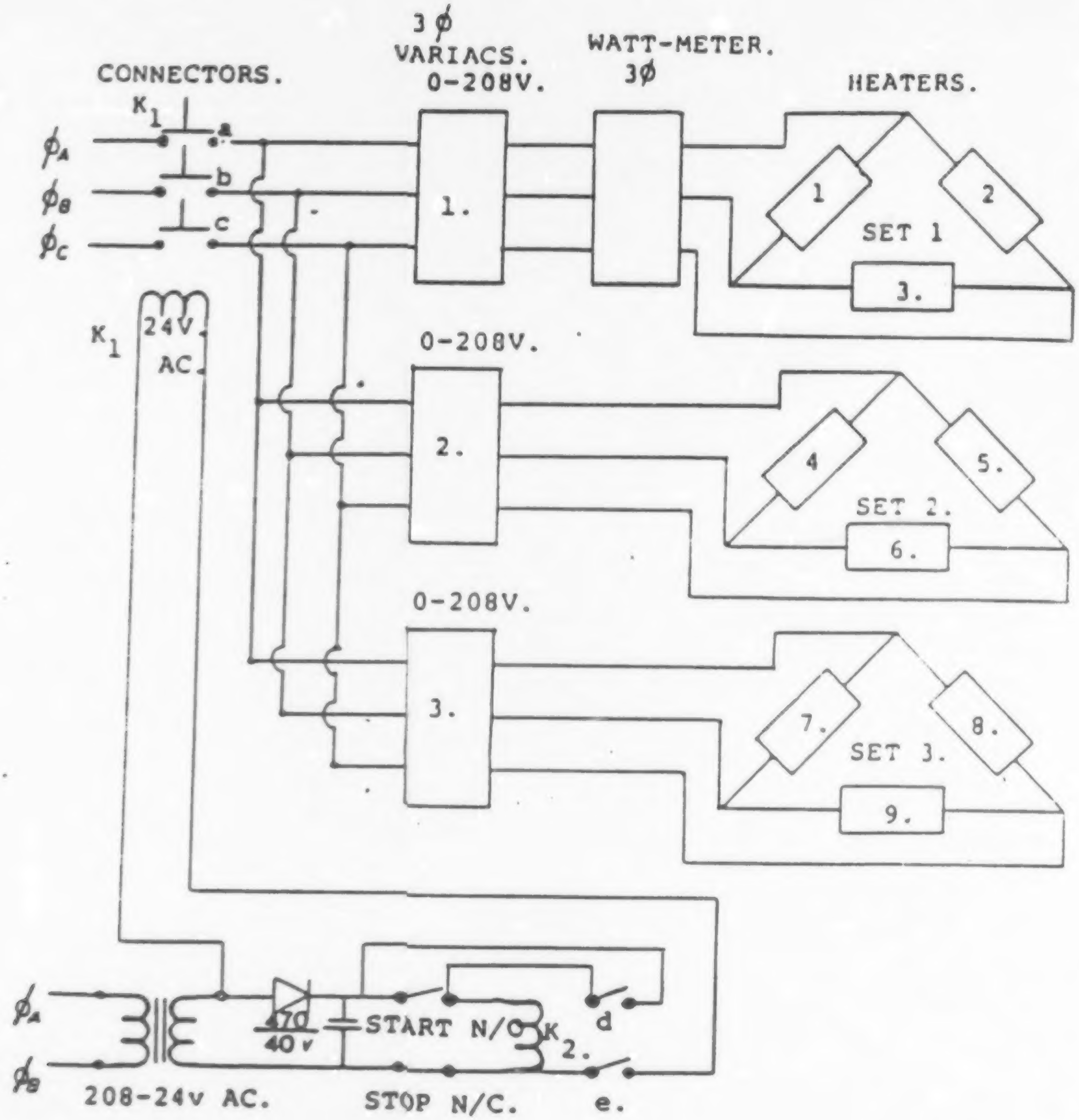
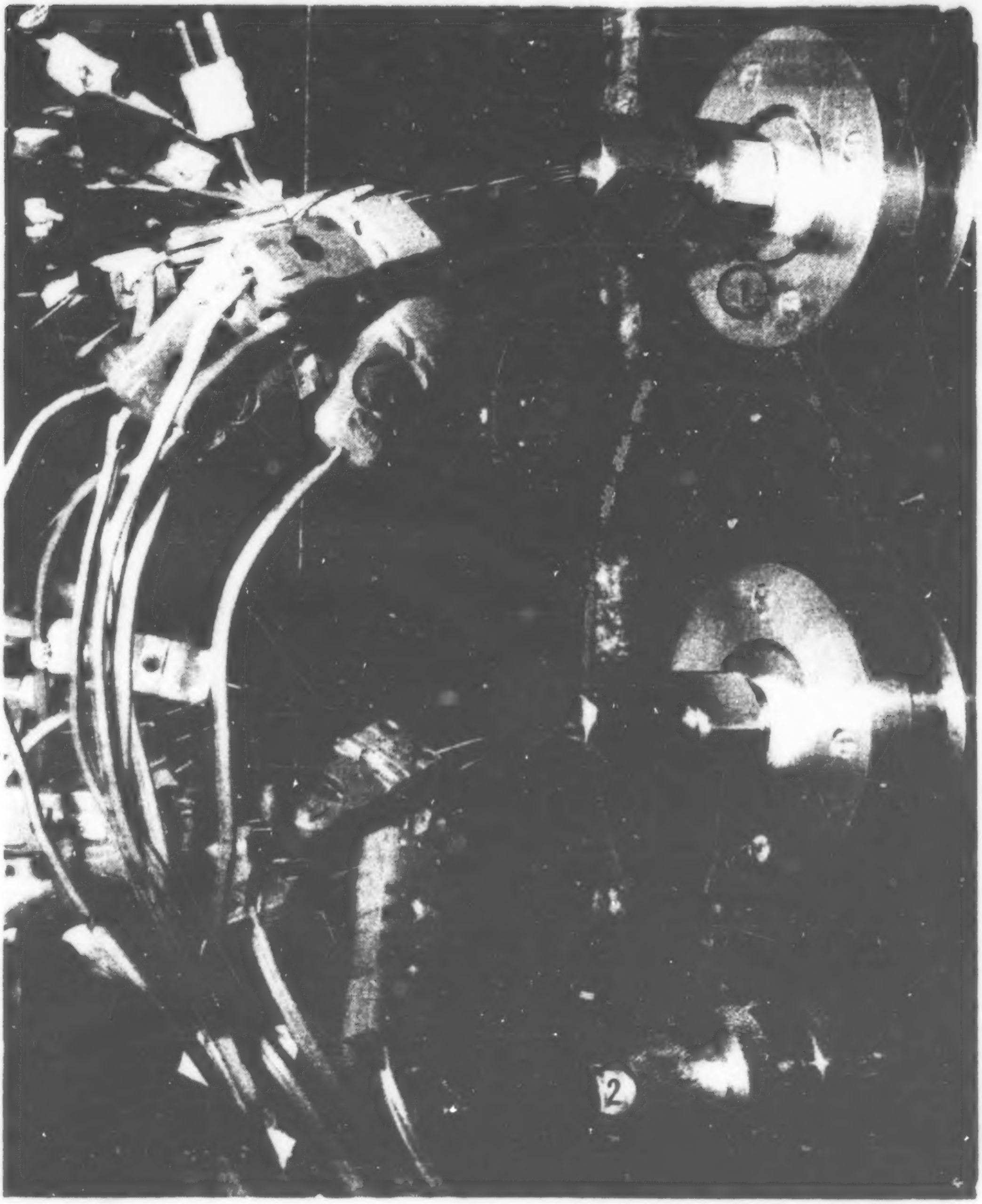
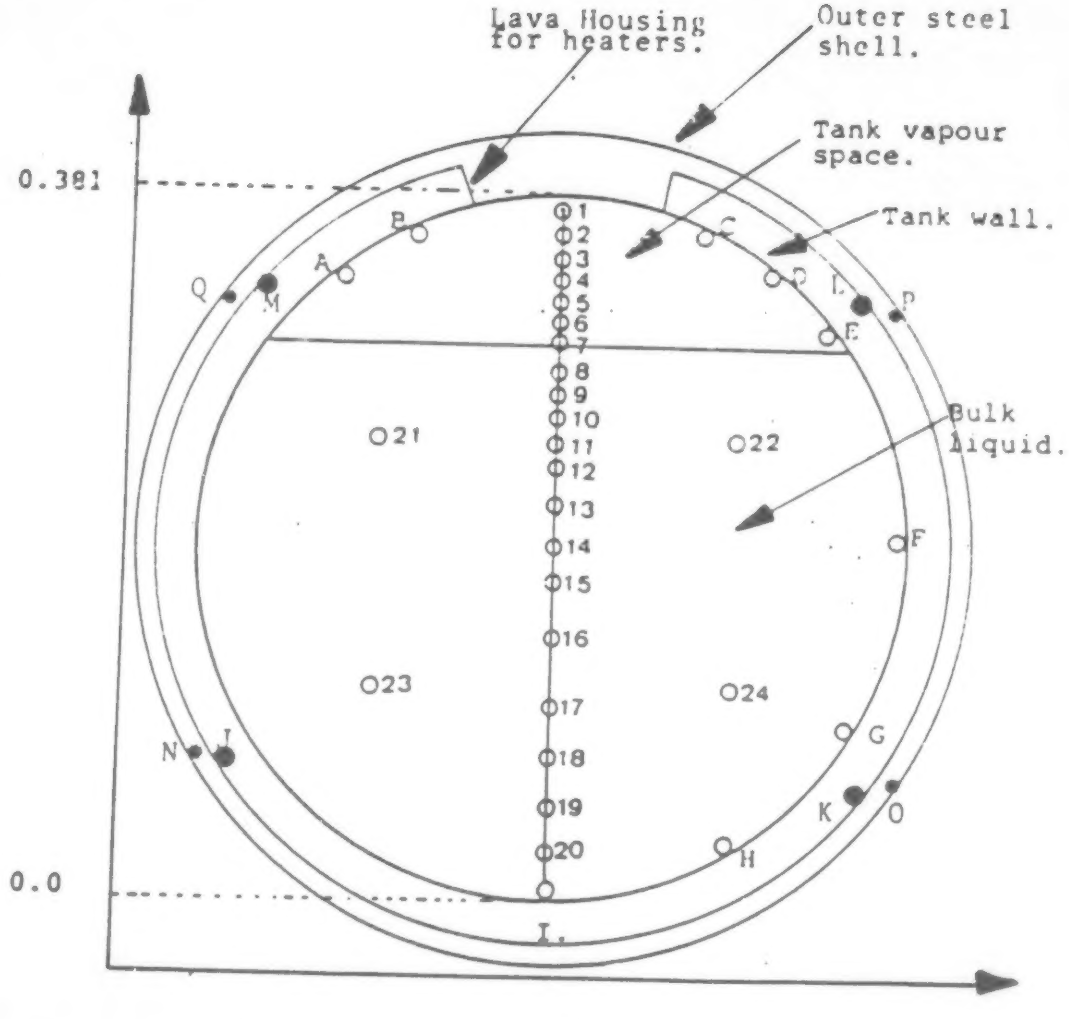


Fig. 2.2(b) Electrical circuit for heaters.



1: Connectors assembly;
2: Inlet port for the loading of Freon-11;
3: Thermocouple connections.

Fig. 2.3(a) Thermocouple-connector assembly.



Inside wall thermocouples	- 9	Iron constantan	(A-I)
Lava housing "	- 4	" "	(J-M)
Outer shell "	- 4	" "	(N-Q)
Fluid "	- 24	Copper "	(1-24)

Fig. 2.3(b) An example of the grid layout of thermocouples.

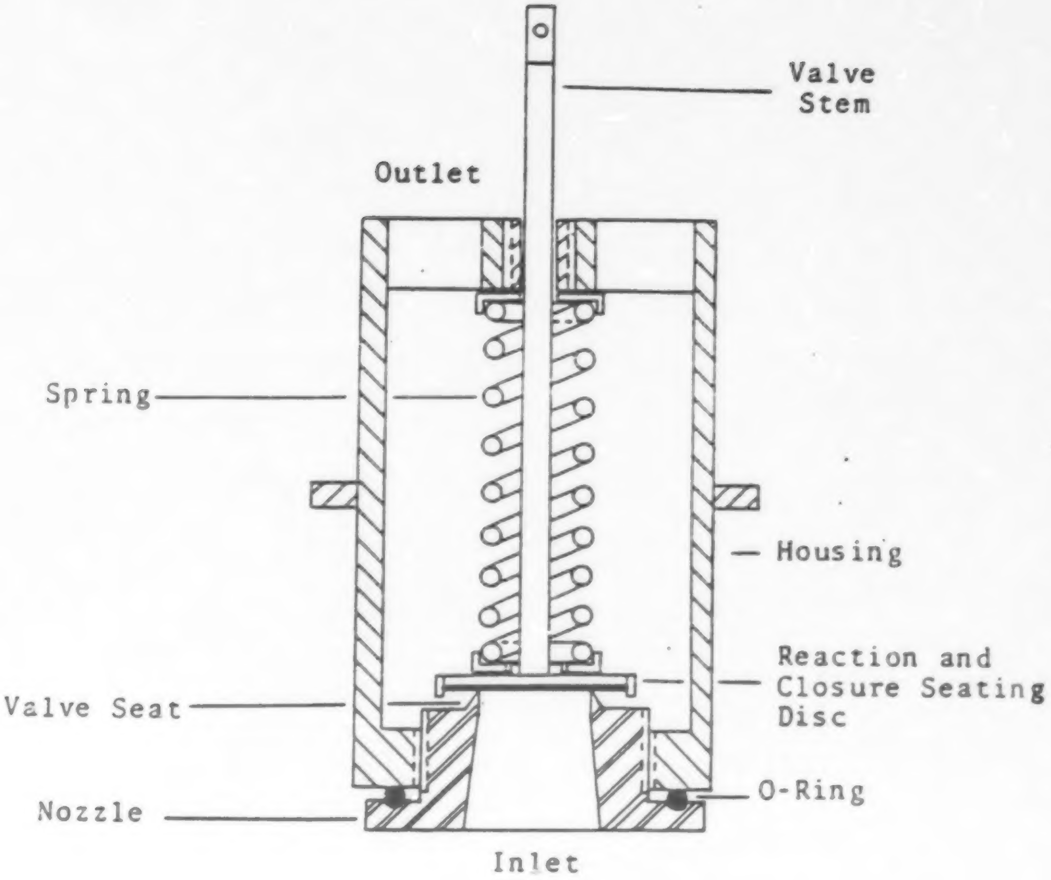


Fig. 2.4 Pressure Relief Valve.

Table 2.1

Experimental program.

TEST #.	Type Protected or Unprotected.	Heat Flux Kw/m^2	PRV Orifice Diameter.	Liquid Level PERCENT.
	PHASE I.			
1.	UNPROTECTED.	10.	3/8"(9.5 mm)	65.
2.	"	65.	1/4"(6.4 mm)	76.
3.	"	65.	"	58
4.	"	65.	"	23.
5.	"	65.	3/8"(9.5 mm)	76.
6.	"	65.	"	58.
7.	"	65.	"	23.
	PHASE II.			
8.	EXPLOSAFE.	40.	3/8"(9.5 mm)	74.
9.	"	40.	"	58.
10.	"	40.	"	23.

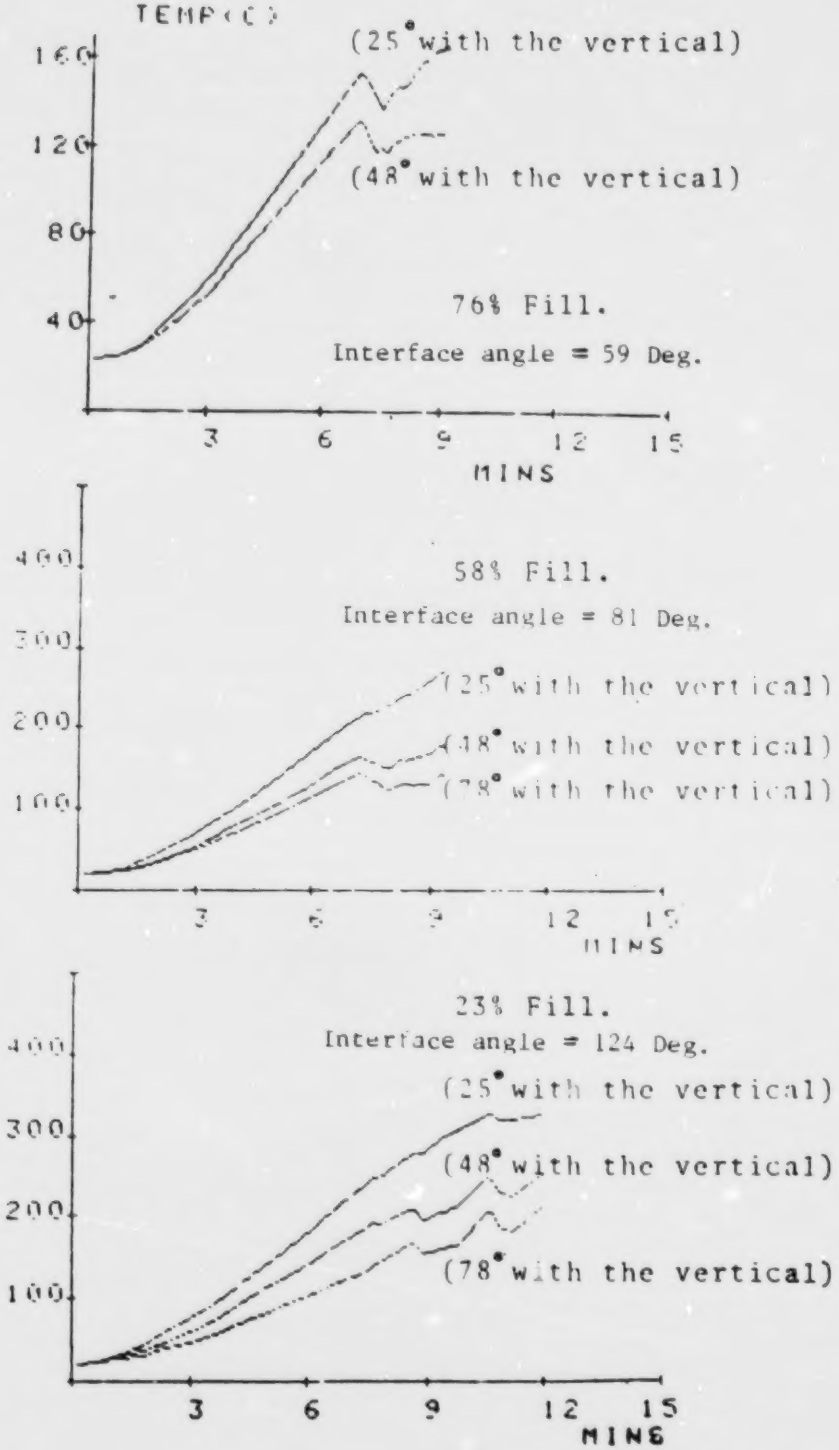


Fig. 3.1 Vapour space wall temperatures versus time for the unprotected vessel with 1/4 in. orifice, for 76, 58 and 23 percent liquid filling. (Q_{IN} =65 KW/m^2).

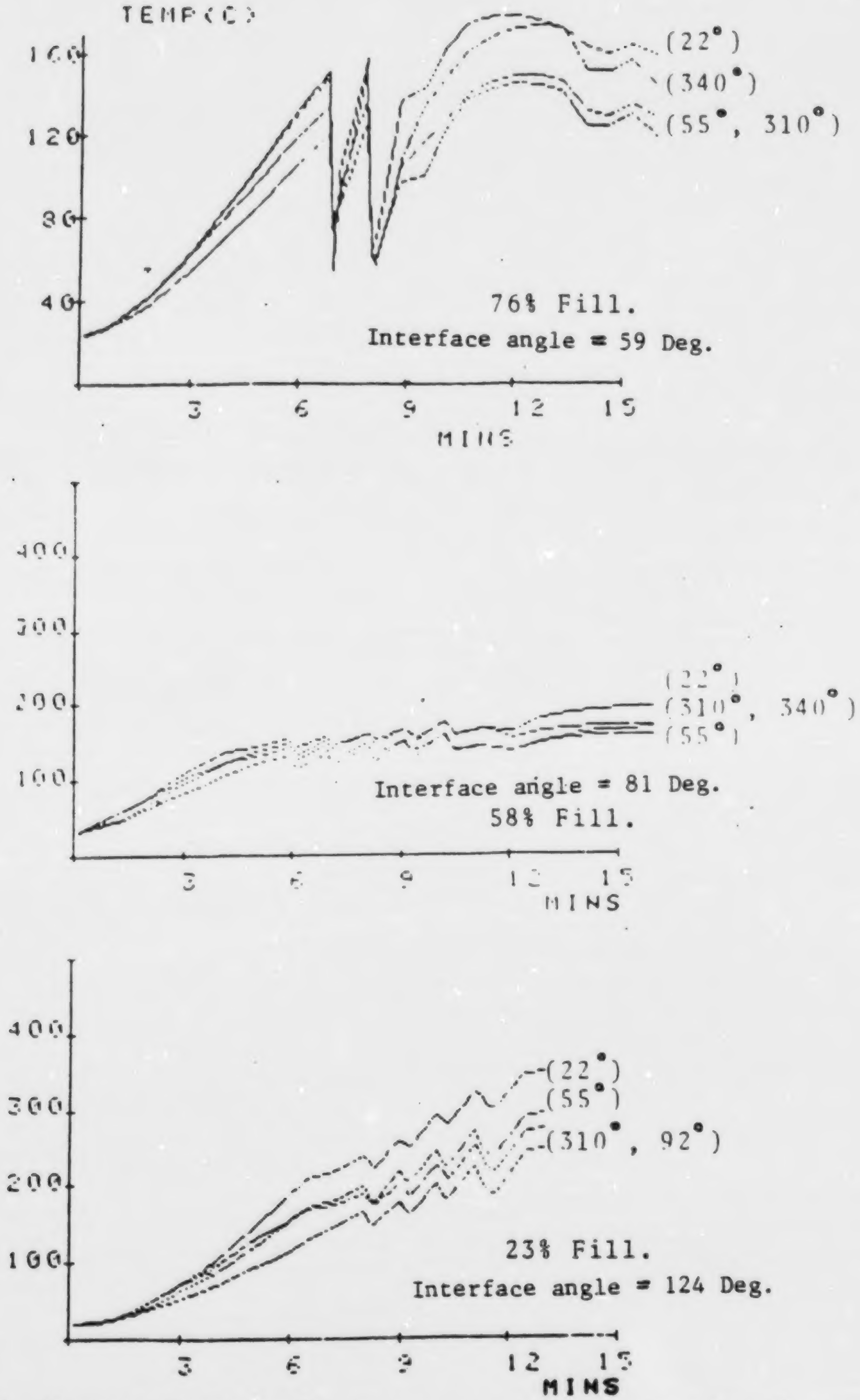
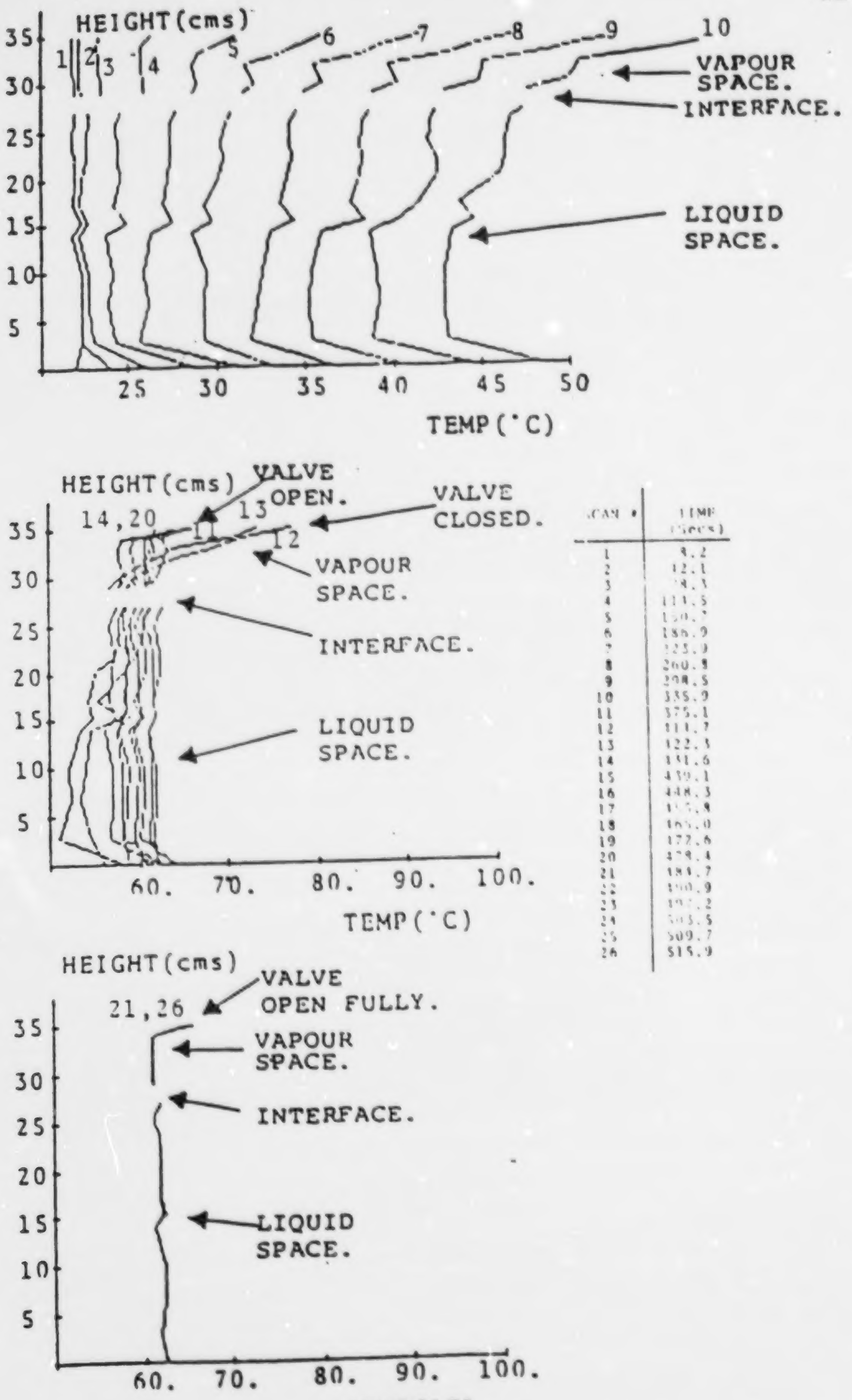
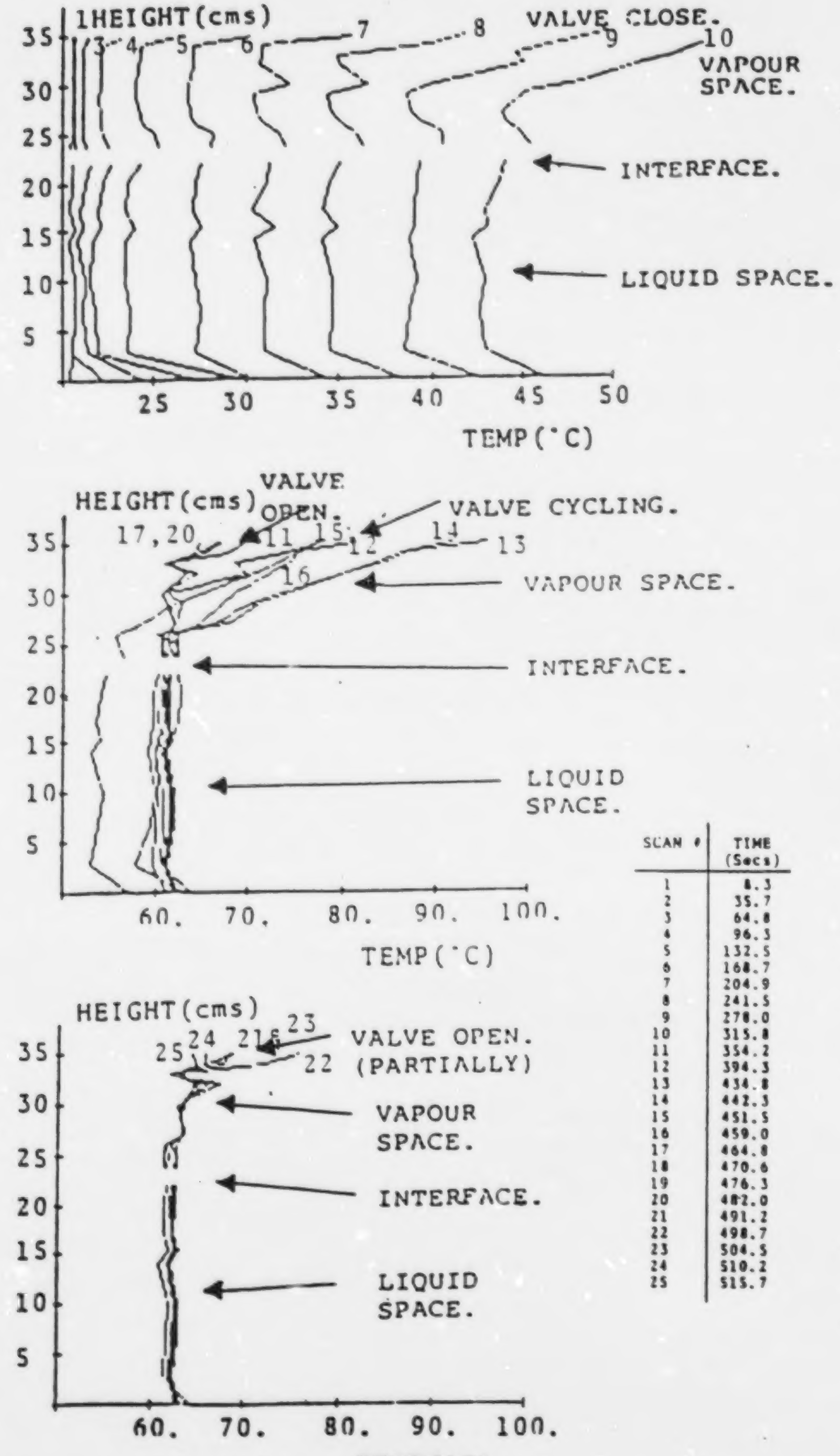


Fig. 3.2 Vapour space wall temperatures versus time for the unprotected vessel with 3/8 in. orifice, for 76, 58 and 23 percent liquid filling. (Q_{IN} = 65 KW/m^2)



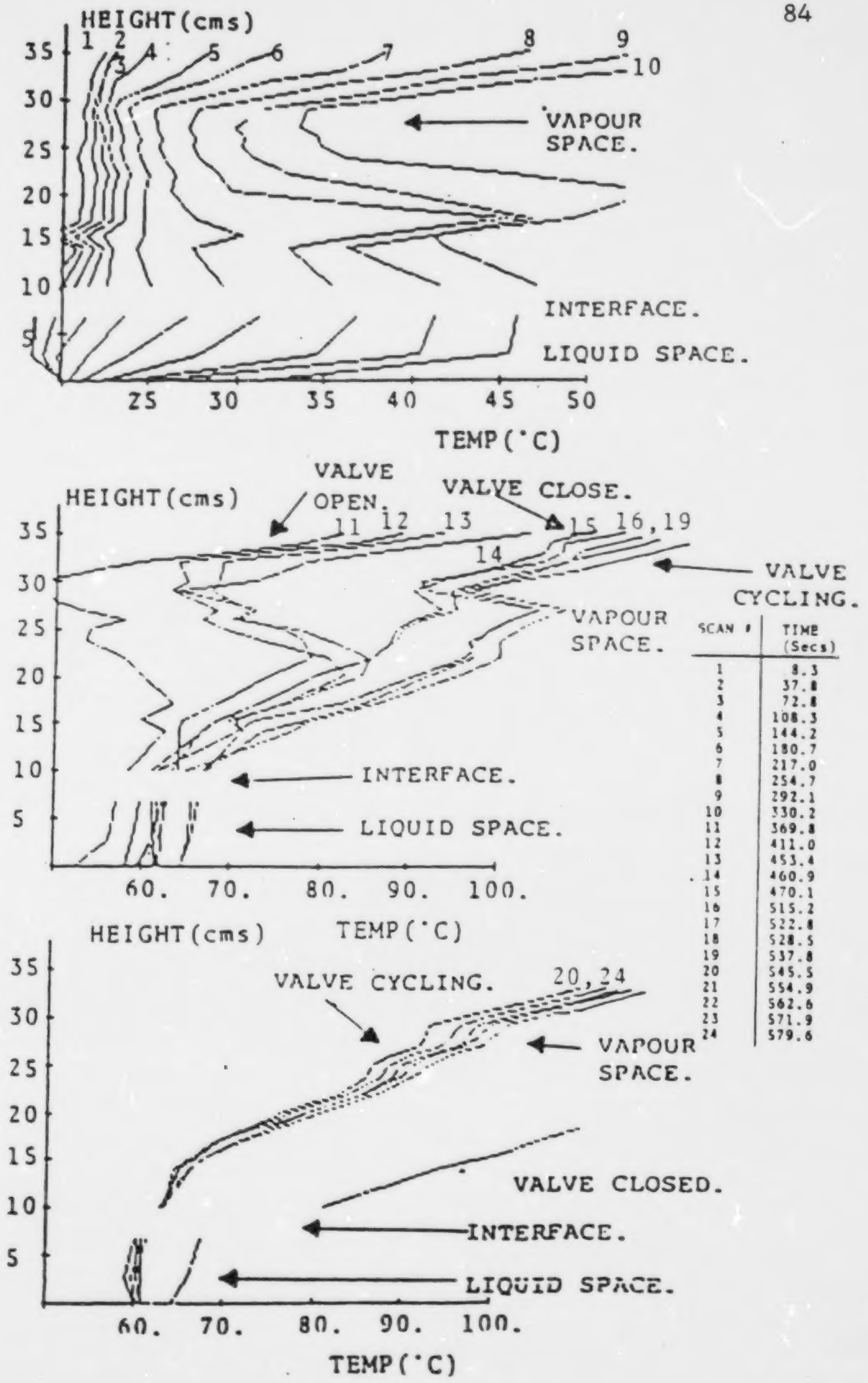
SCAN #	TIME (Secs)
1	4.2
2	42.1
3	78.3
4	111.5
5	150.7
6	186.9
7	223.9
8	260.9
9	298.5
10	335.9
11	375.1
12	411.7
13	422.3
14	431.6
15	439.1
16	448.3
17	455.8
18	465.0
19	472.6
20	479.4
21	484.7
22	490.9
23	497.2
24	503.5
25	509.7
26	515.9

Fig. 3.3 Stratification in the unprotected vessel with 1/4 in. orifice, for 76% liquid fill(Q_{IN}=65 KW/m^2)



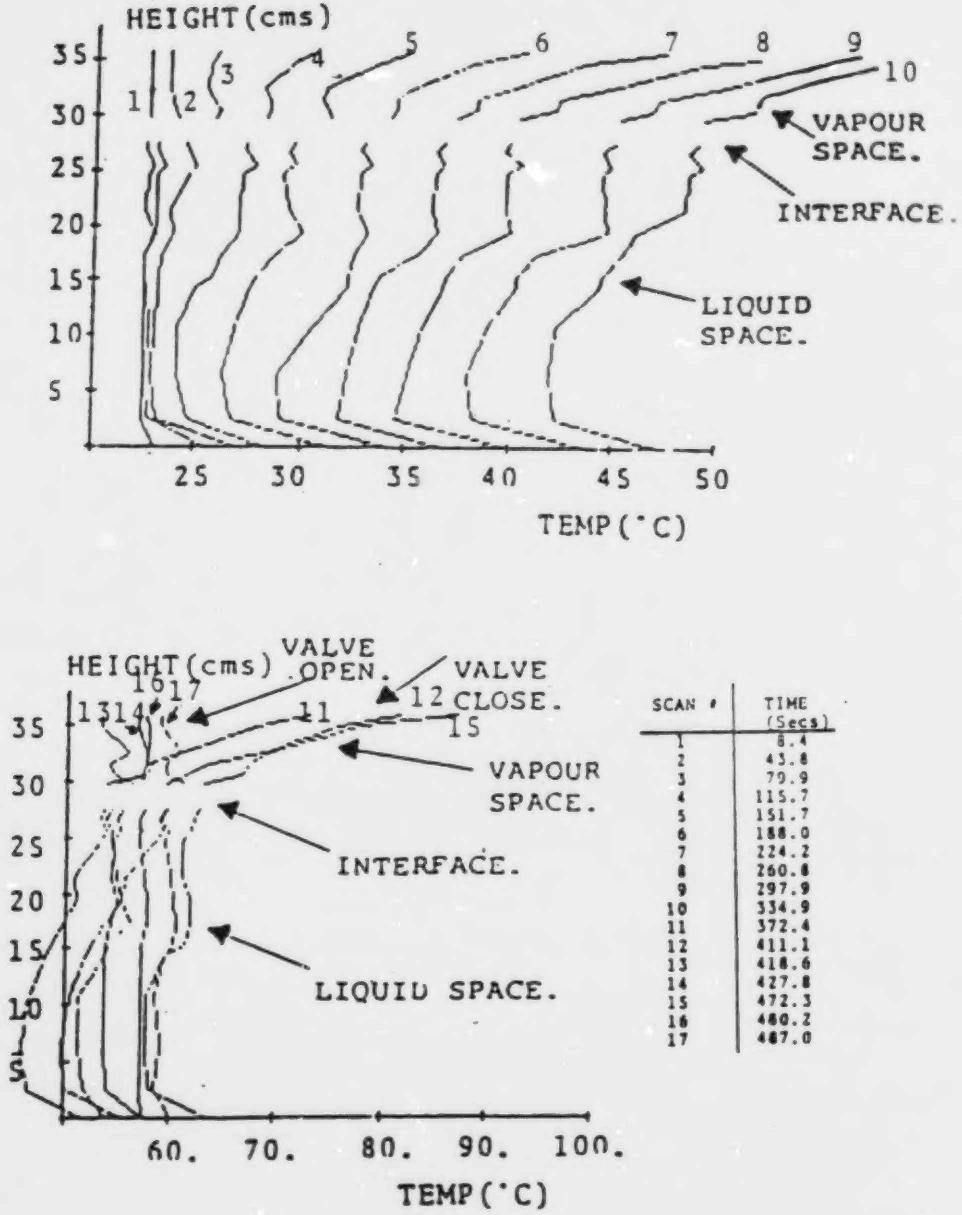
SCAN #	TIME (Secs)
1	8.3
2	35.7
3	64.8
4	96.3
5	132.5
6	168.7
7	204.9
8	241.5
9	278.0
10	315.8
11	354.2
12	394.3
13	434.8
14	442.3
15	451.5
16	459.0
17	464.8
18	470.6
19	476.3
20	482.0
21	491.2
22	498.7
23	504.5
24	510.2
25	515.7

Fig. 3.4 Stratification in the unprotected vessel with 1/4 in. orifice, for 58% liquid fill(Q_{IN}=65 KW/m^2)



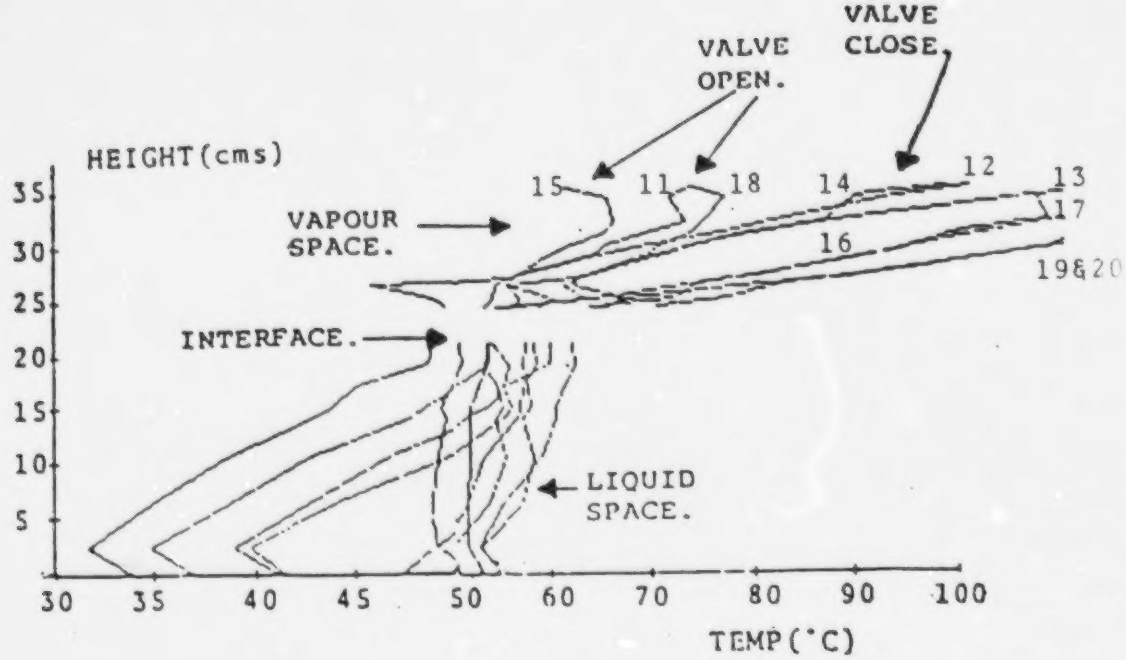
SCAN #	TIME (Secs)
1	8.3
2	37.8
3	72.8
4	108.3
5	144.2
6	180.7
7	217.0
8	254.7
9	292.1
10	330.2
11	369.8
12	411.0
13	453.4
14	460.9
15	470.1
16	515.2
17	522.8
18	528.5
19	537.8
20	545.5
21	554.9
22	562.6
23	571.9
24	579.6

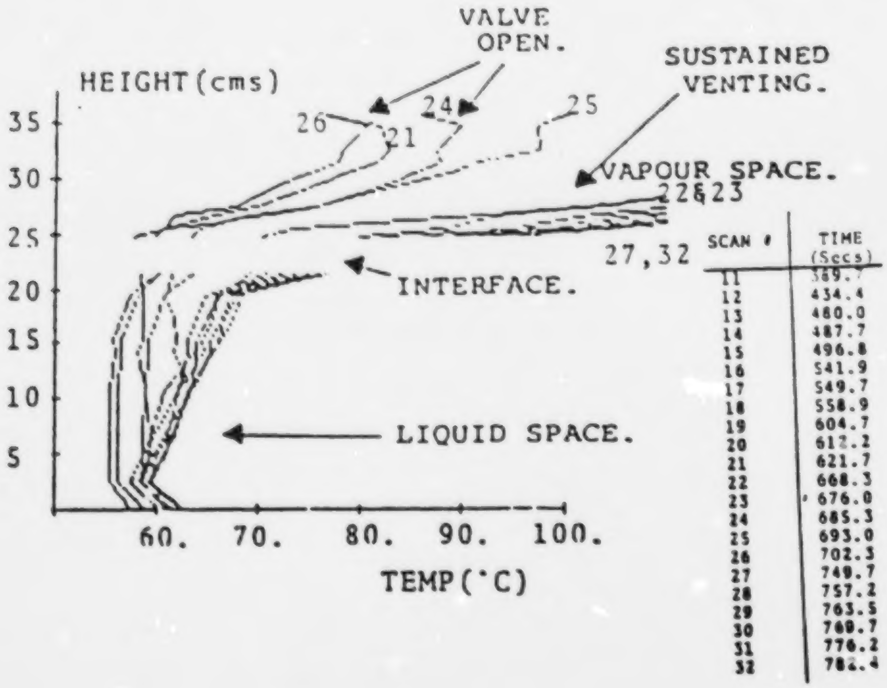
Fig. 3.5 Stratification in the unprotected vessel with 1/4 in. orifice, for 23% liquid fill(Q_{IN}=65 KW/m^2)



SCAN #	TIME (Secs)
1	8.4
2	43.8
3	79.9
4	115.7
5	151.7
6	188.0
7	224.2
8	260.8
9	297.9
10	334.9
11	372.4
12	411.1
13	418.6
14	427.8
15	472.3
16	480.2
17	487.0

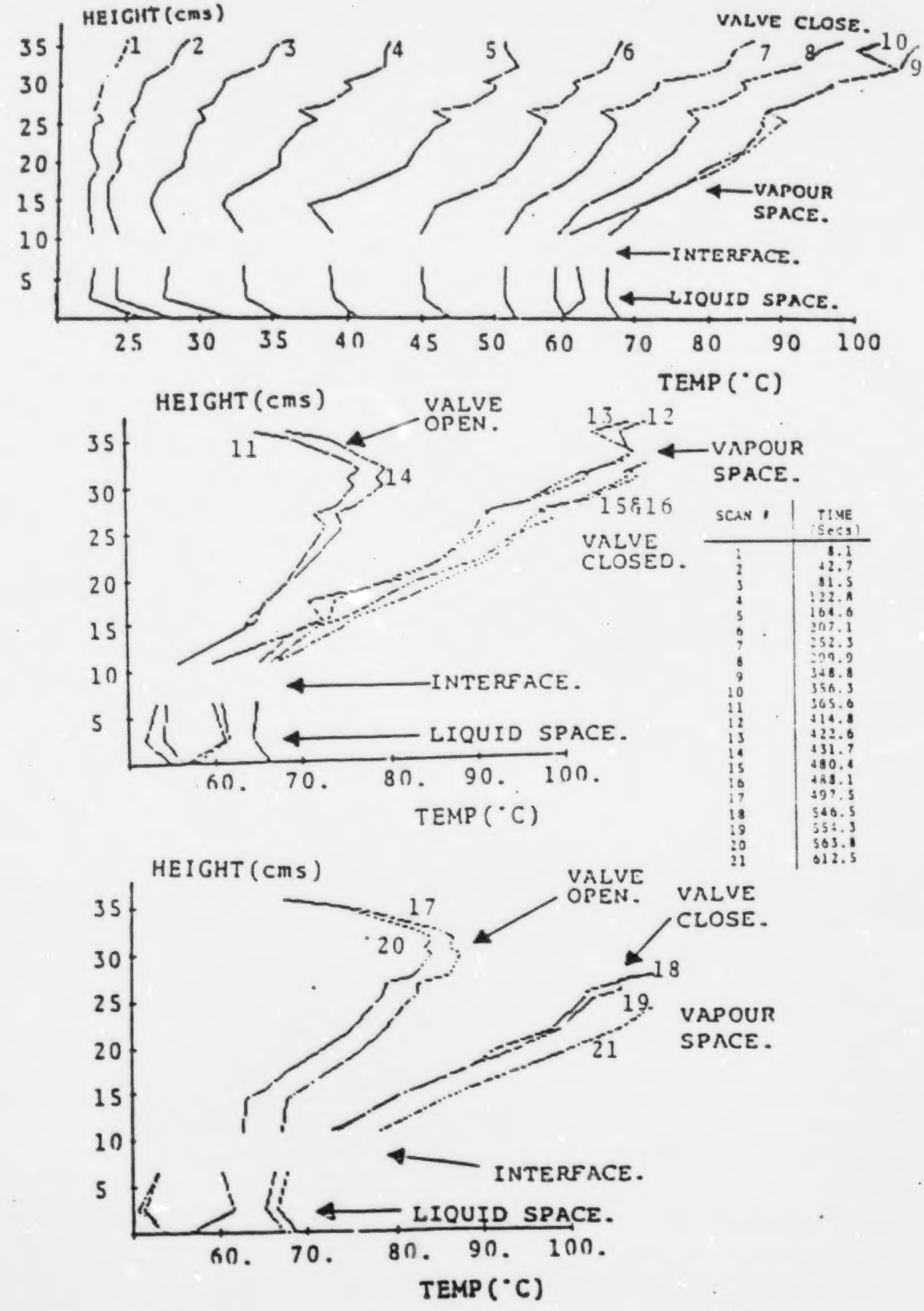
Fig. 3.6 Stratification in the unprotected vessel with 3/8 in. orifice, for 76% liquid fill(Q_{IN}=65 KW/m^2)





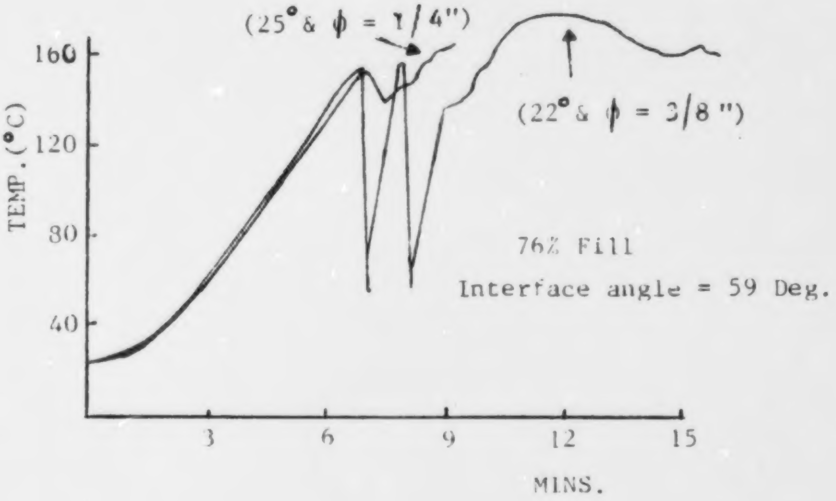
SCAN #	TIME (Secs)
11	389.7
12	434.4
13	480.0
14	487.7
15	496.8
16	541.9
17	549.7
18	558.9
19	604.7
20	612.2
21	621.7
22	668.3
23	676.0
24	685.3
25	693.0
26	702.3
27	749.7
28	757.2
29	763.5
30	769.7
31	776.2
32	782.4

Fig. 3.7 Stratification in the unprotected vessel with 3/8 in. orifice, for 58% liquid fill(Q_{IN}=65 KW/m^2)

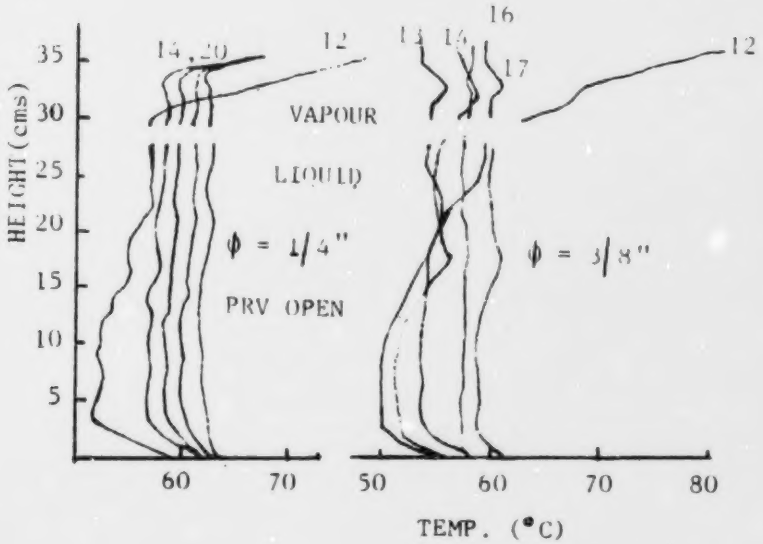


SCAN #	TIME (Secs)
1	8.1
2	42.7
3	81.5
4	122.8
5	164.6
6	207.1
7	252.3
8	299.9
9	348.8
10	356.3
11	365.6
12	414.8
13	422.6
14	431.7
15	480.4
16	488.1
17	497.5
18	546.5
19	554.3
20	563.8
21	612.5

Fig. 3.8 Stratification in the unprotected vessel with 3/8 in. orifice, for 23% liquid fill(Q_{IN}=65 KW/m^2)



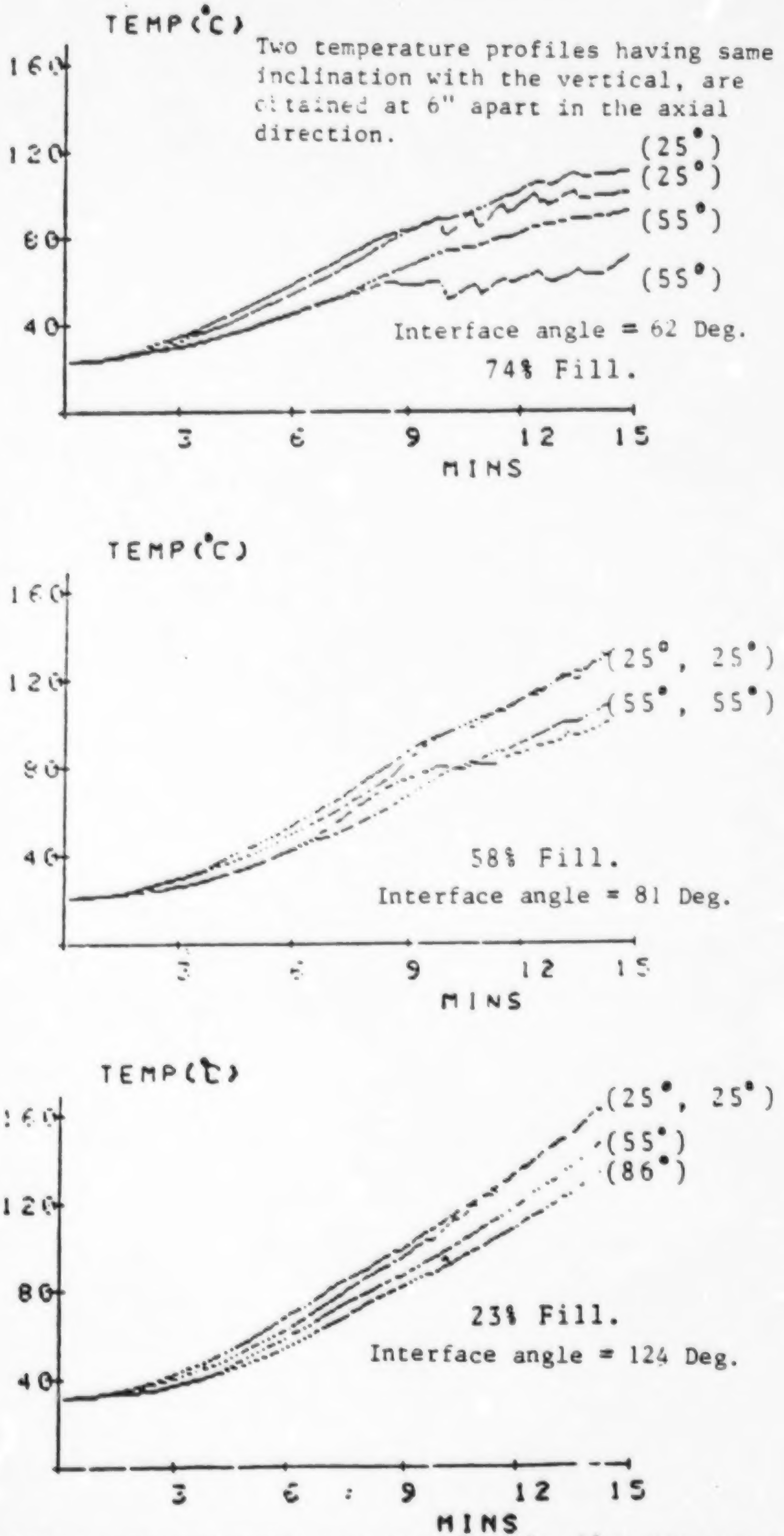
- Vapour space wall temperature profiles versus time.



- Vapour-liquid temperature profiles versus vessel height.

NOTE· Time can be obtained for the scan numbers from Figs. 3.3 & 3.6

Fig. 3.9 A comparison of wall and vapour temperature profiles for the two PRV orifices (Q_{IN} = 65 KW/m^2 , Liquid level=76% and interface angle=59 deg.)



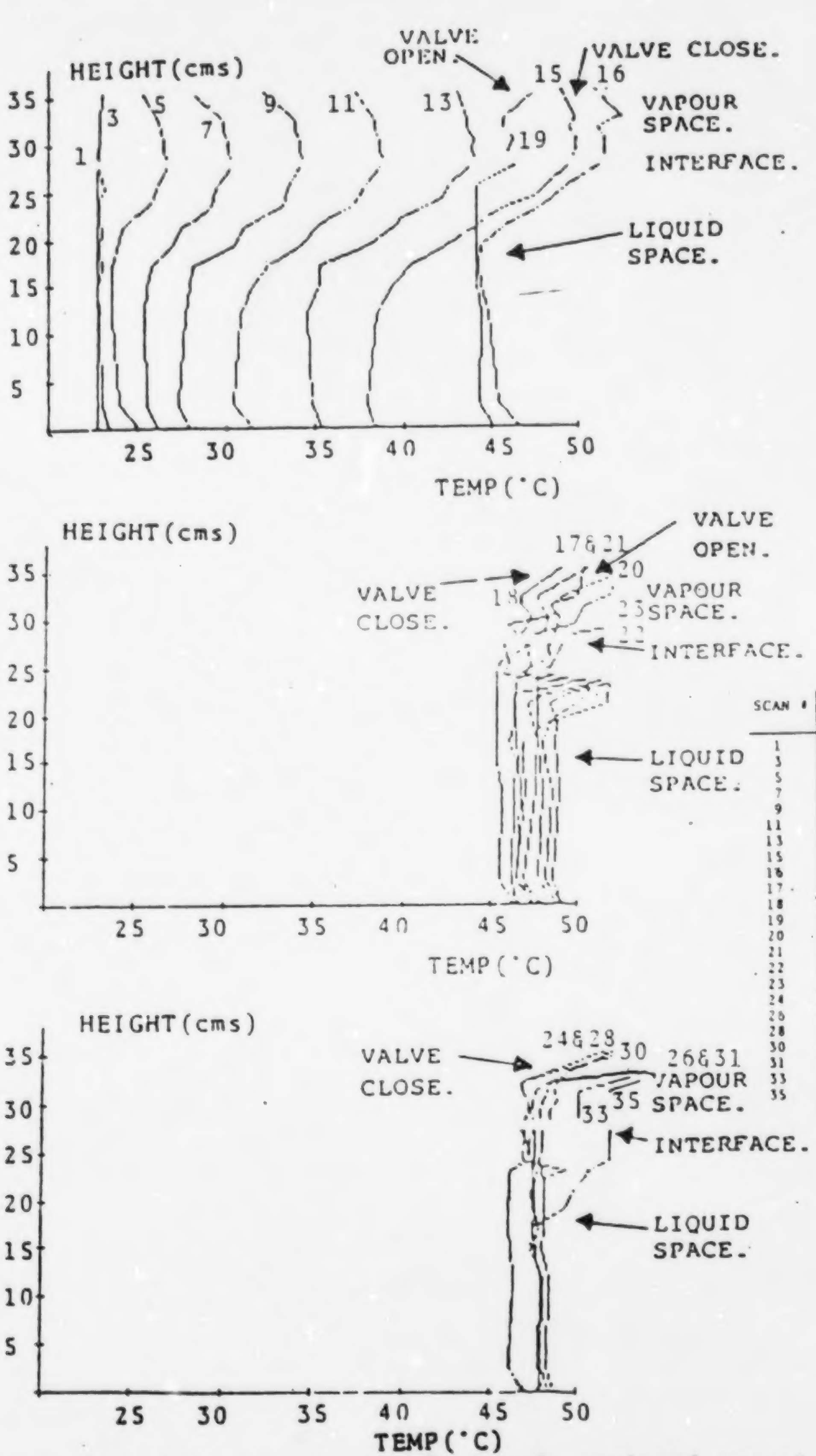
Two temperature profiles having same inclination with the vertical, are obtained at 6" apart in the axial direction.

Interface angle = 62 Deg.
74% Fill.

58% Fill.
Interface angle = 81 Deg.

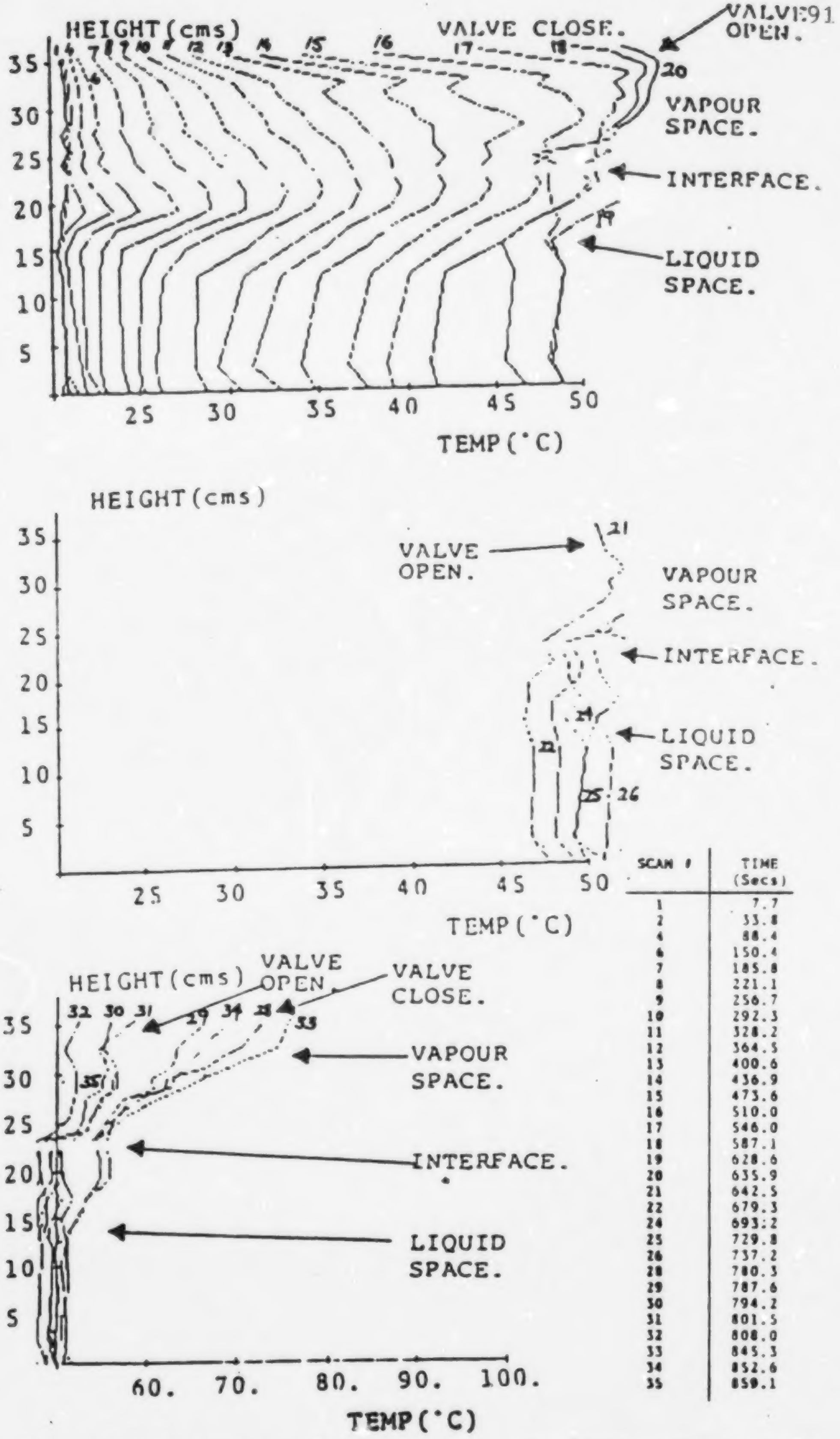
23% Fill.
Interface angle = 124 Deg.

Fig. 3.10 Wall temperatures versus time in the vapour space of the Explosafe equipped vessel, when liquid levels are 74, 58 and 23%. (Q_{IN}=40 KW/m^2)



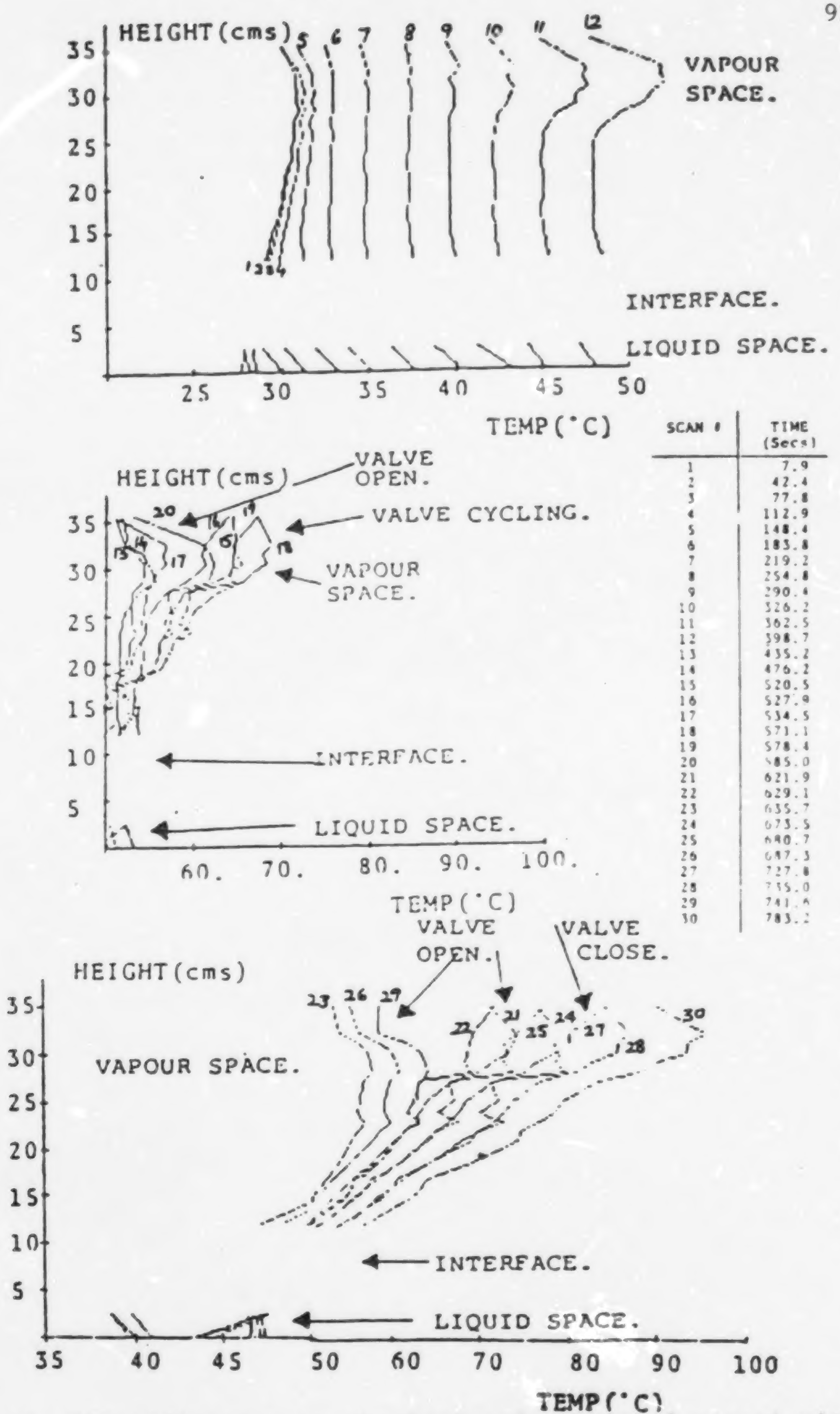
SCAN #	TIME (Secs)
1	7.9
3	77.9
5	148.2
7	218.8
9	289.9
11	361.9
13	434.6
15	507.7
16	548.7
17	589.9
18	597.1
19	603.7
20	640.2
21	647.5
22	654.0
23	690.5
24	697.9
26	740.9
28	754.7
30	768.6
31	804.9
33	818.8
35	892.2

Fig. 3.11 Stratification in the Explosafe equipped vessel with 3/8 in. PRV orifice for 74% liquid fill(Q_{IN}=40 KW/m^2)



SCAN #	TIME (Secs)
1	7.7
2	33.8
4	88.4
6	150.4
7	185.8
8	221.1
9	256.7
10	292.3
11	328.2
12	364.5
13	400.6
14	436.9
15	473.6
16	510.0
17	546.0
18	587.1
19	628.6
20	635.9
21	642.5
22	679.3
24	693:2
25	729.8
26	737.2
28	780.3
29	787.6
30	794.2
31	801.5
32	808.0
33	845.3
34	852.6
35	859.1

Fig. 3.12 Stratification in the Explosafe equipped vessel with 3/8 in. PRV orifice for 58% liquid fill(Q_{IN}=40 KW/m^2)



SCAN #	TIME (Secs)
1	7.9
2	42.4
3	77.8
4	112.9
5	148.4
6	183.8
7	219.2
8	254.8
9	290.4
10	326.2
11	362.5
12	398.7
13	435.2
14	476.2
15	520.5
16	527.9
17	534.5
18	571.1
19	578.4
20	585.0
21	621.9
22	629.1
23	635.7
24	673.5
25	680.7
26	687.3
27	727.8
28	735.0
29	741.6
30	783.2

Fig. 3.13 Stratification in the Explosafe equipped vessel with 3/8 in. PRV orifice for 23% liquid fill(Q_{IN}=40 KW/m^2)

Table 4.1 Temperature of the heater wire as a function of time. (Q_{IN} = 65 KW/m^2, Liquid level = 76% and PRV orifice = 1/4 in.)

TIME (seconds)	T_{WIRE} with the argon gas. (Deg. C)	T_{WIRE} with Air. (Deg. C)
8.285	598.0	586.0
78.285	598.0	586.0
150.73	600.0	589.0
223.9	605.0	595.0
298.5	610.0	601.0
375.11	617.0	609.0
431.6	621.0	613.0
465.08	625.0	617.0
503.45	628.0	621.0

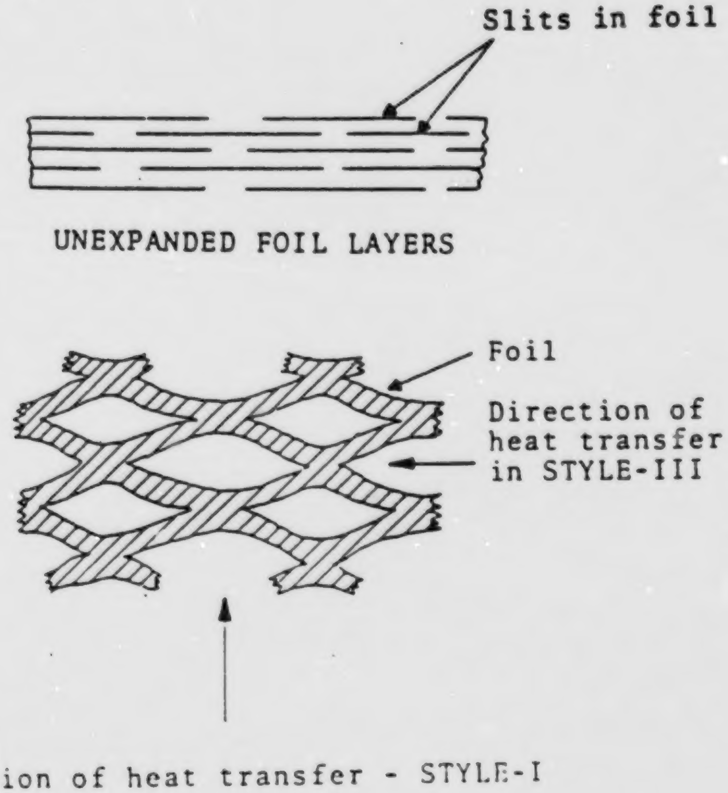

Slits in foil
UNEXPANDED FOIL LAYERS
Foil
Direction of heat transfer in STYLE-III
Direction of heat transfer - STYLE-I

Fig. 4.1 Heat transfer in Explosafe.

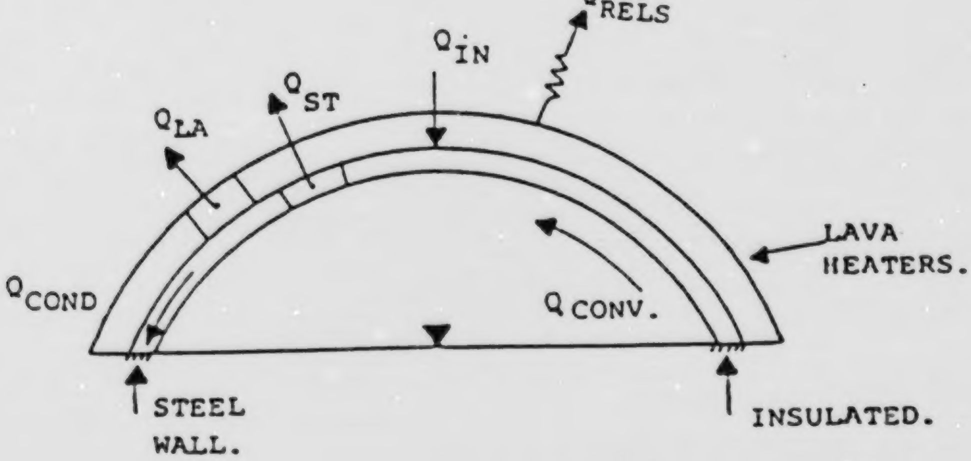


Fig. 4.2 Model for the heat transfer in the vapour space of the UNB vessel equipped with and without Explosafe.

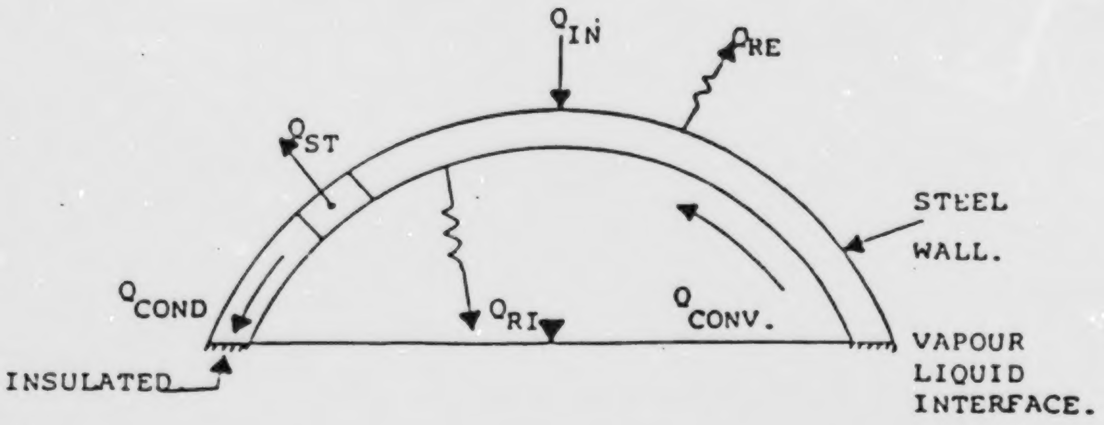


Fig. 4.3 Model for the heat transfer in the vapour space of an unprotected vessel.

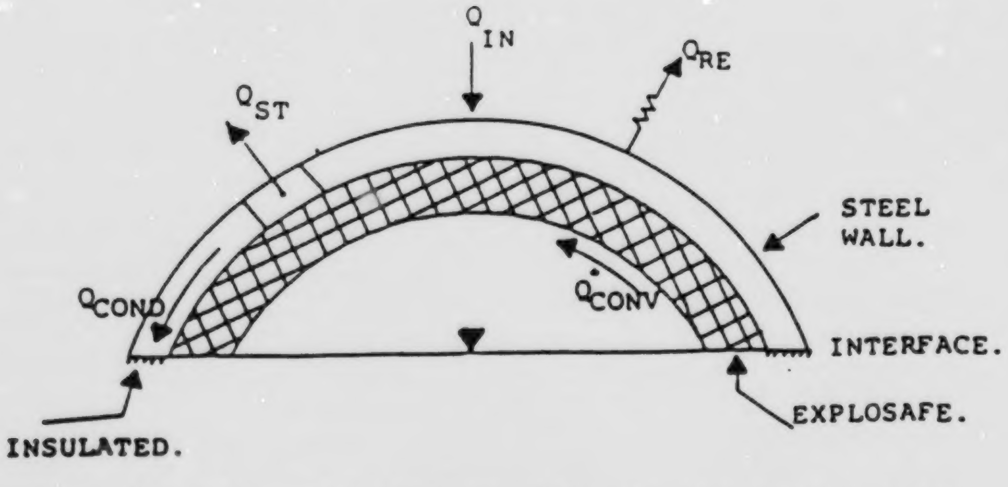
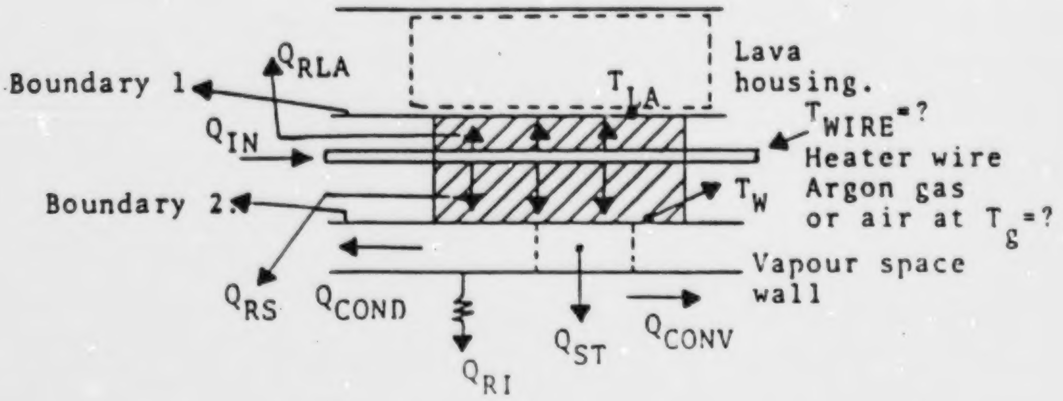


Fig. 4.4 Model for the heat transfer in the vapour space of the Explosafe equipped vessel



Analysis is based on the shaded control volume.

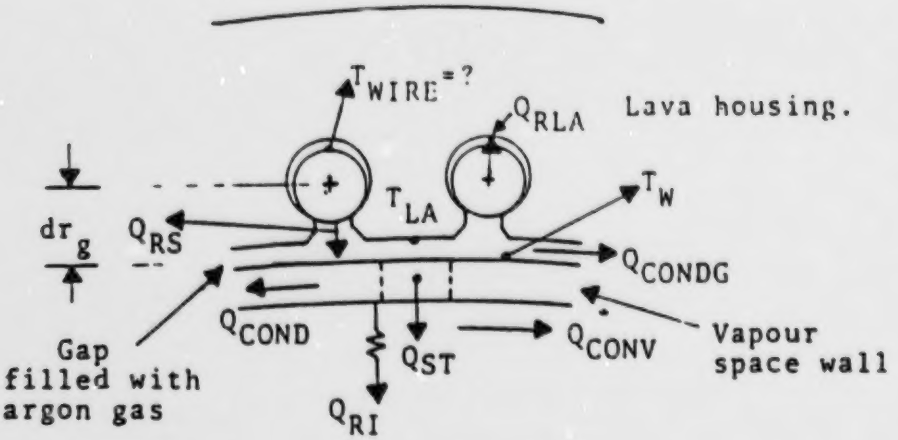


Fig. 4.5 Model to determine the heat transfer in the vapour space of the UNB vessel(an alternate method)

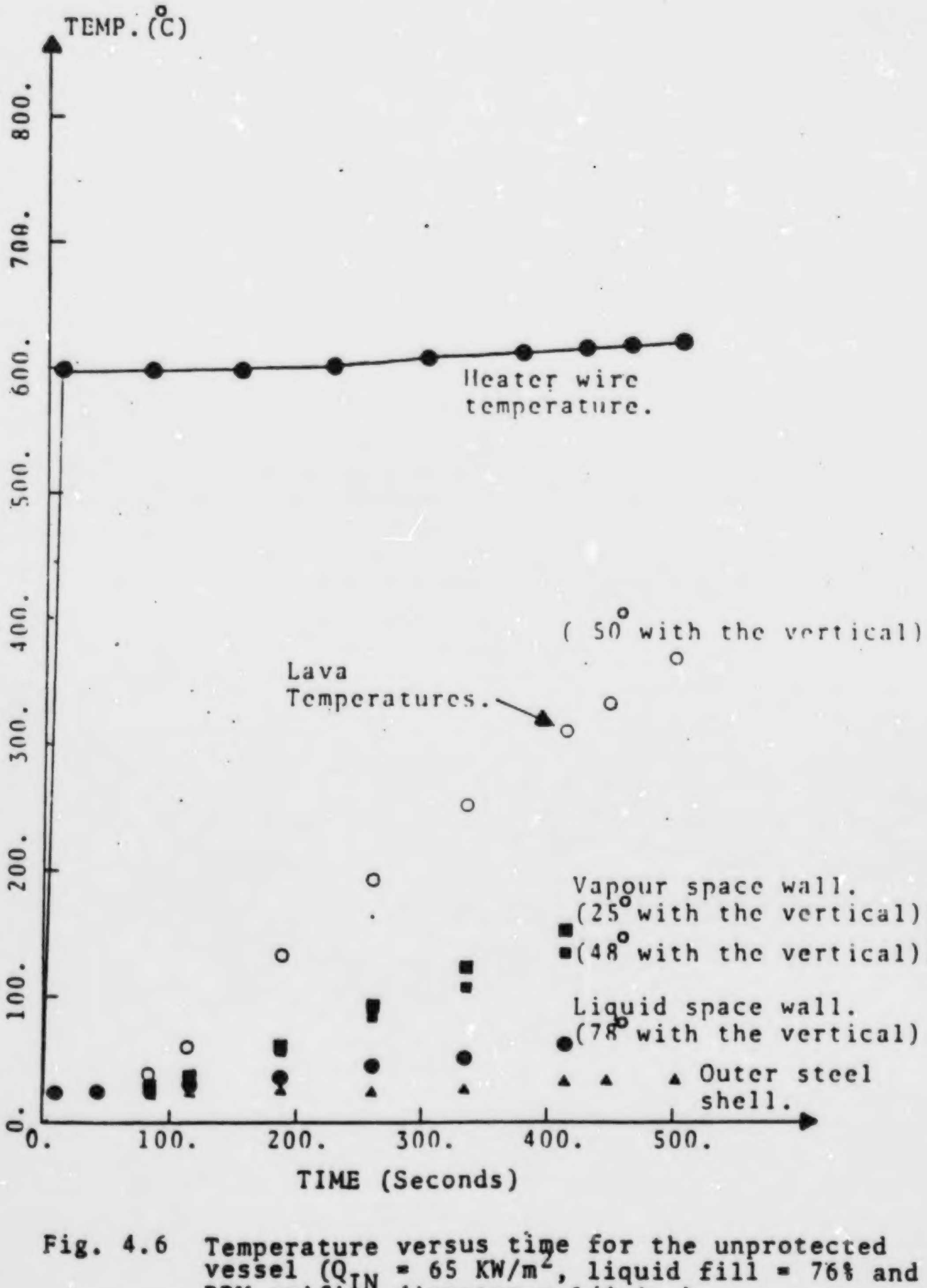


Fig. 4.6 Temperature versus time for the unprotected vessel (Q_{IN} = 65 KW/m^2, liquid fill = 76% and PRV orifice diameter = 1/4 in.)

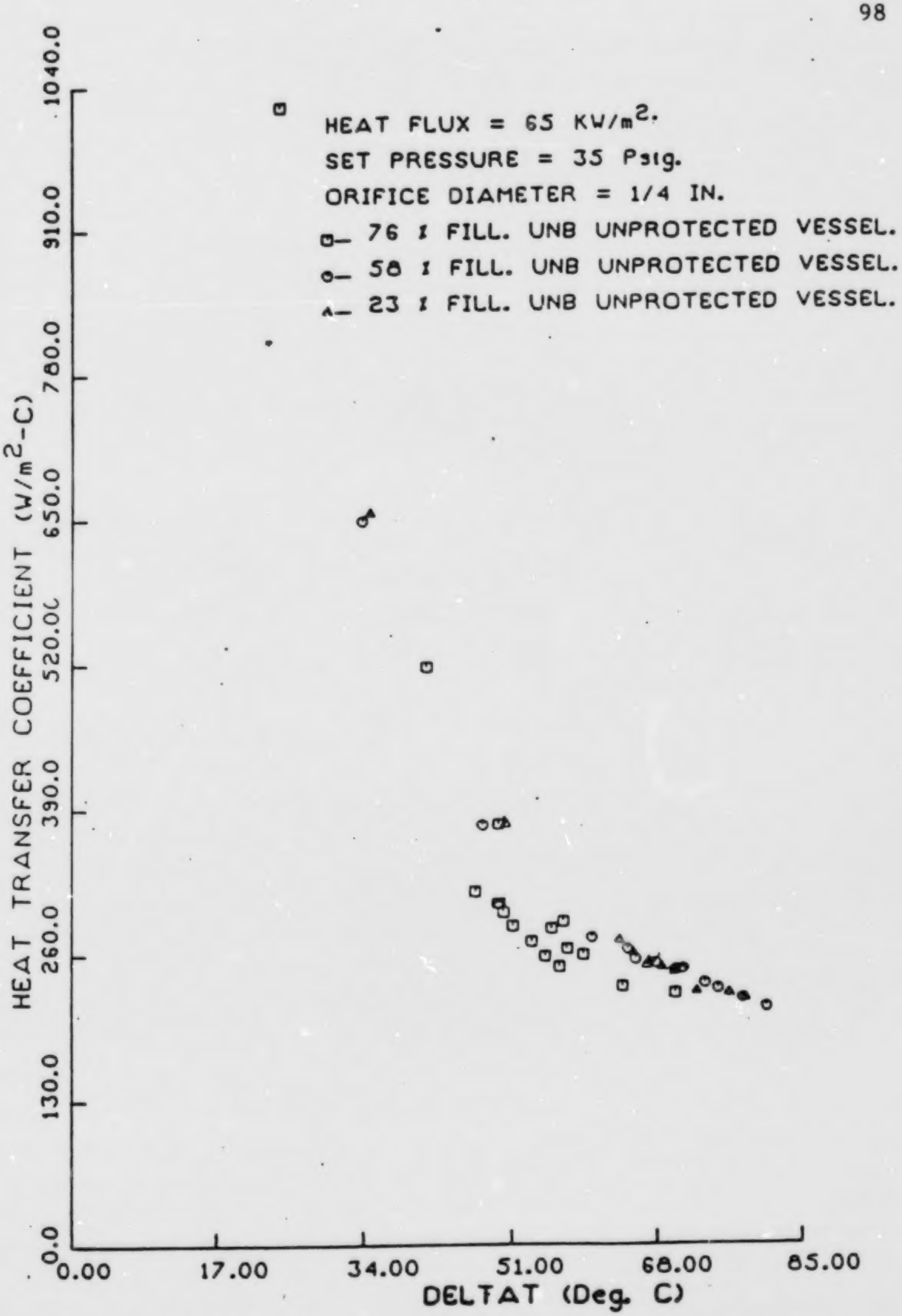


Fig. 4.7 Heat transfer coefficient versus temperature difference for the unprotected vessel with 1/4 in. valve orifice diameter.

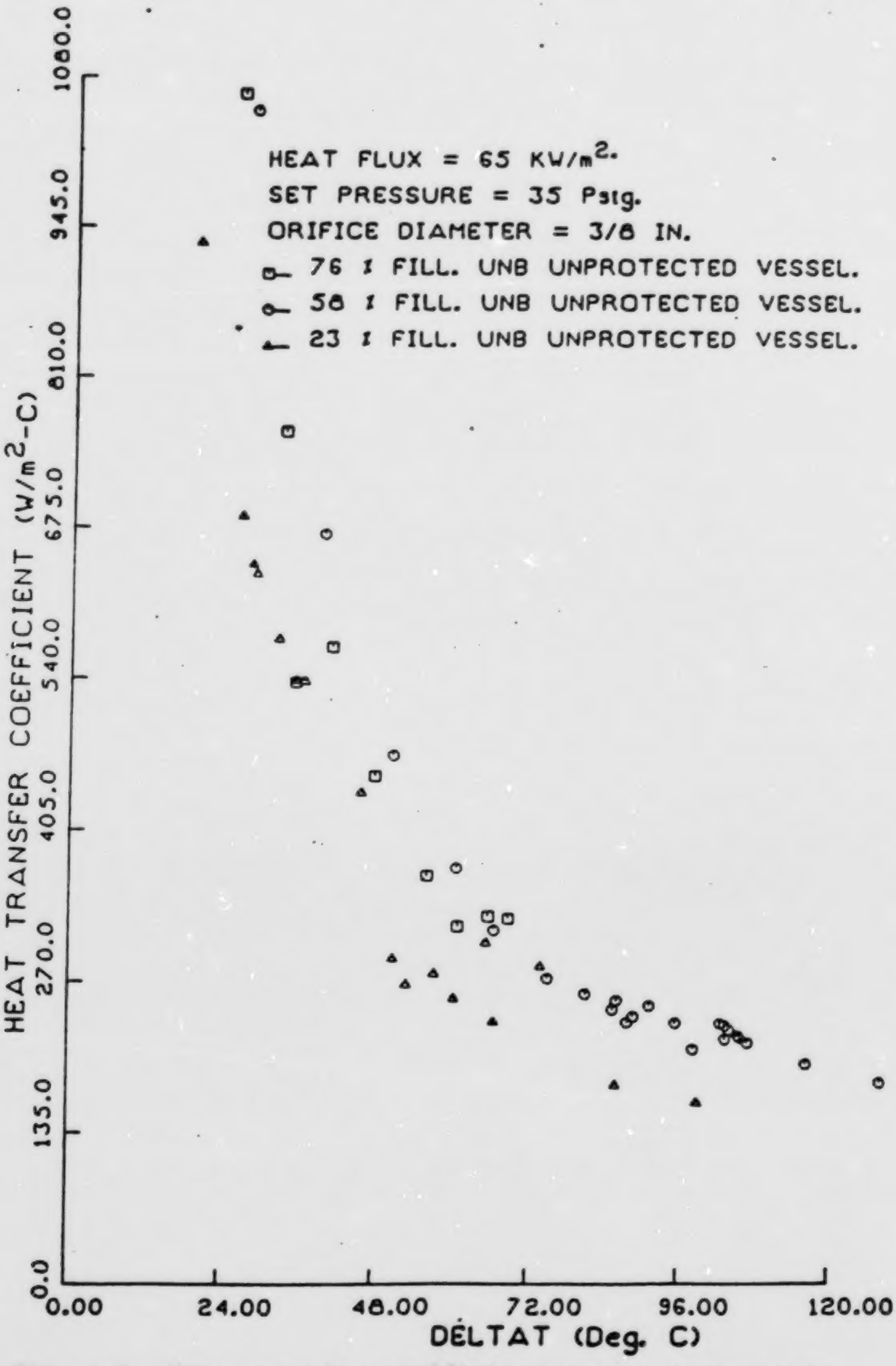


Fig. 4.8 Heat transfer coefficient versus temperature difference for the unprotected vessel with 3/8 in. valve orifice diameter.

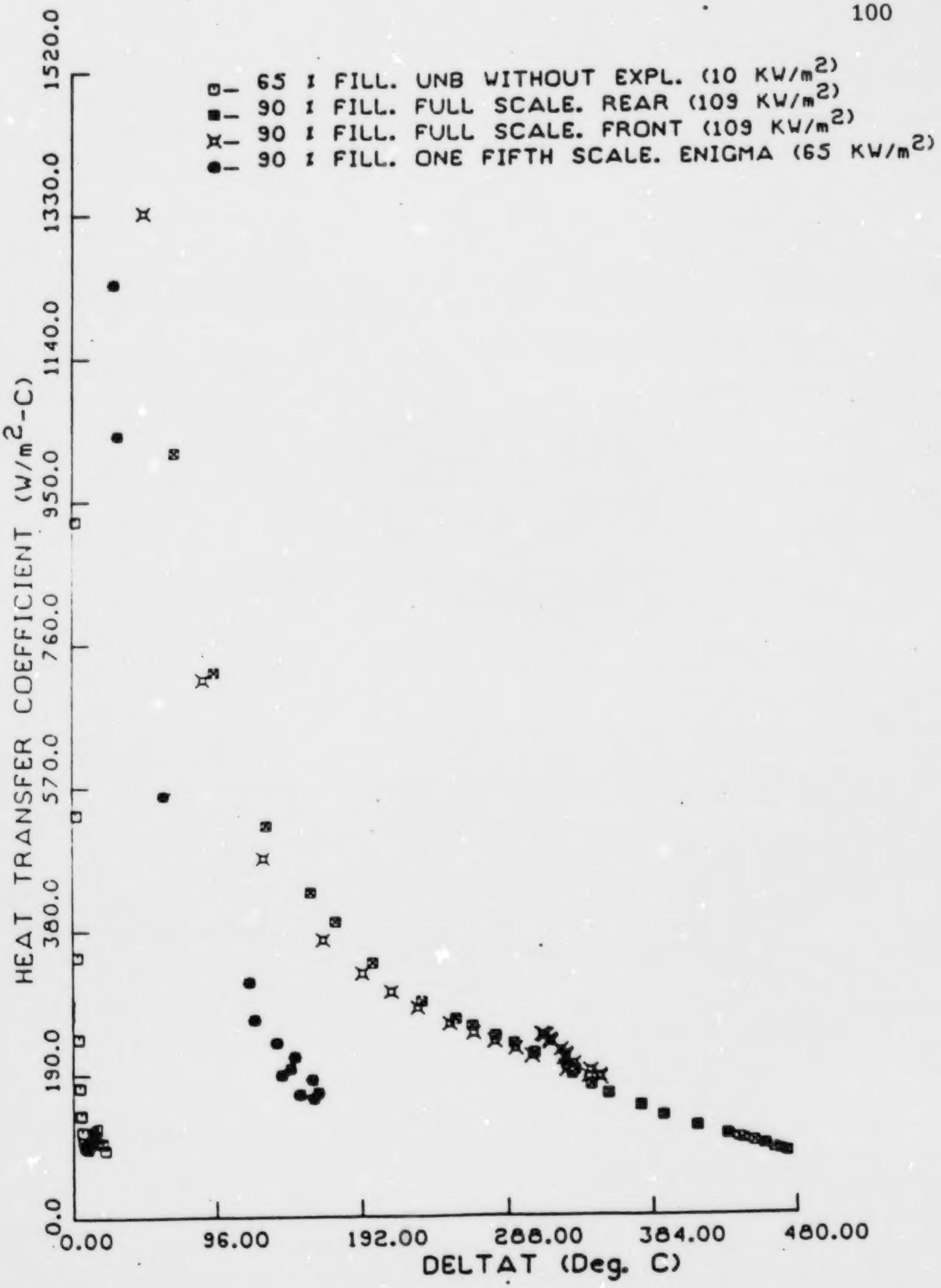


Fig. 4.9 Heat transfer coefficient versus temperature difference for unprotected vessels (full-scale, one-fifth scale and UNB tanks)

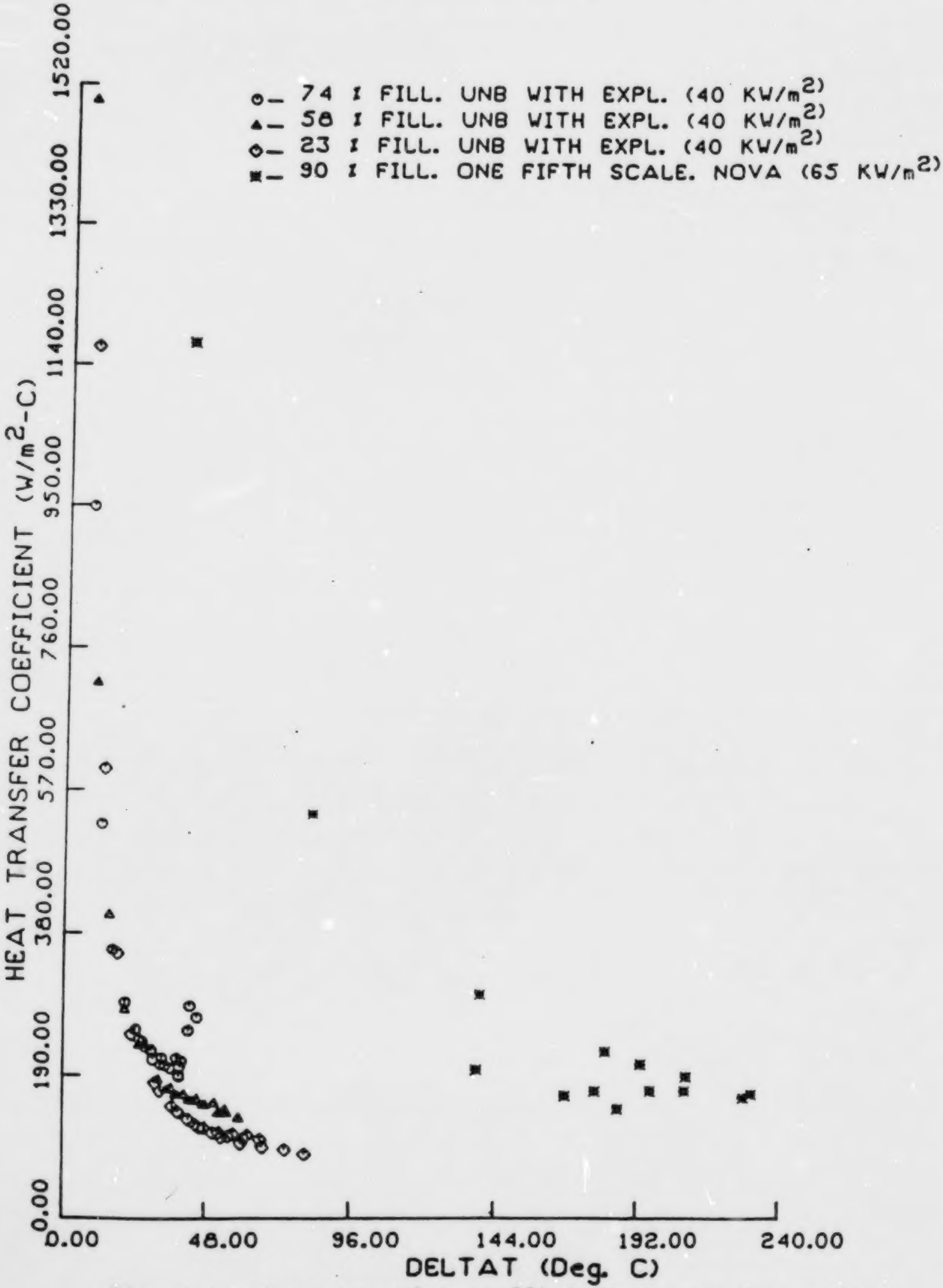


Fig. 4.10 Heat transfer coefficient versus temperature difference for Explosafe equipped vessels.

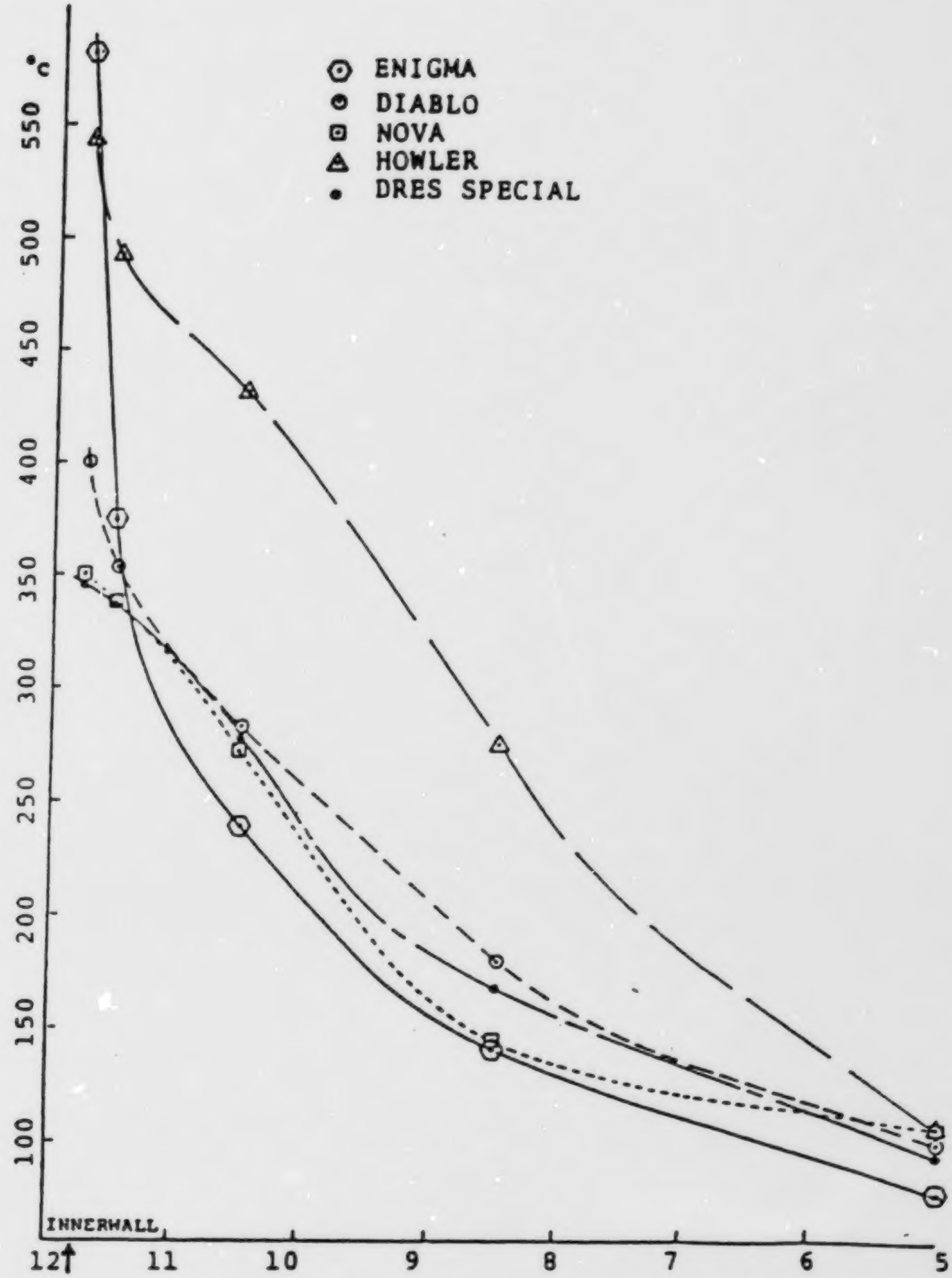


Fig. 4.11 Vertical radial temperature profile with vessels 60% liquid full.

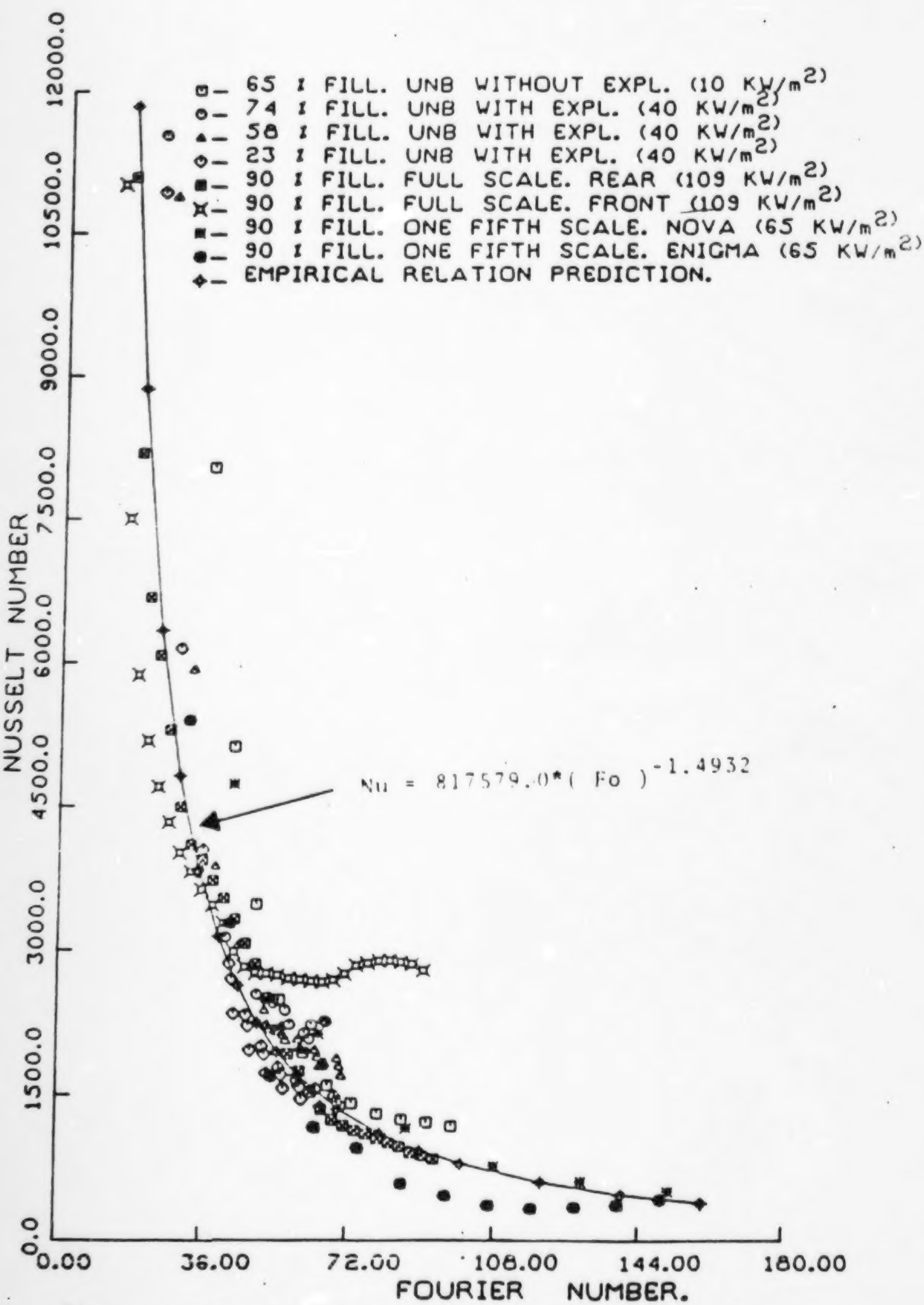


Fig. 4.12 Graph between Nusselt and Fourier numbers for general correlation.

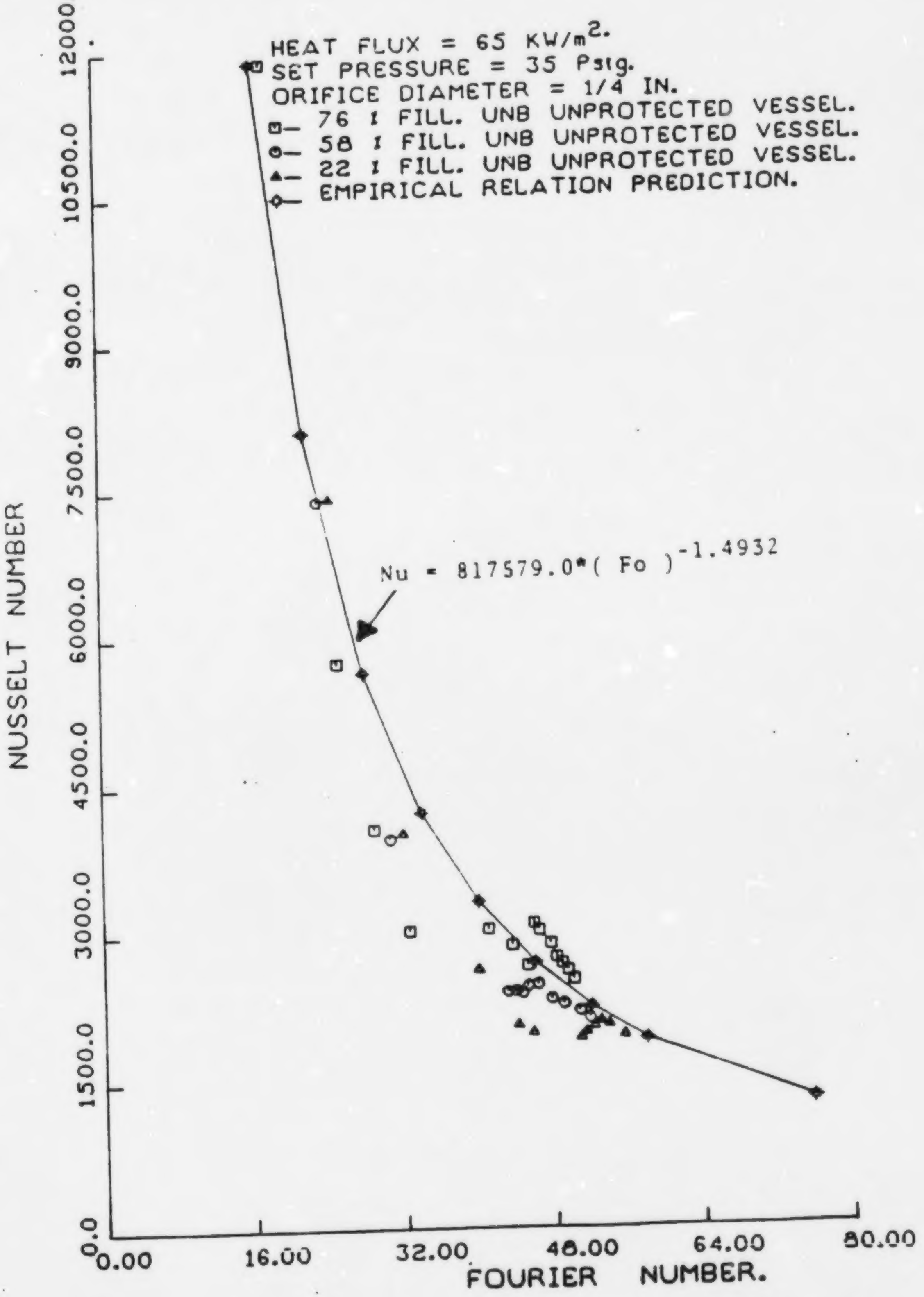


Fig. 4.13 Nusselt number versus Fourier number for the unprotected tank with 1/4 in. orifice diameter.

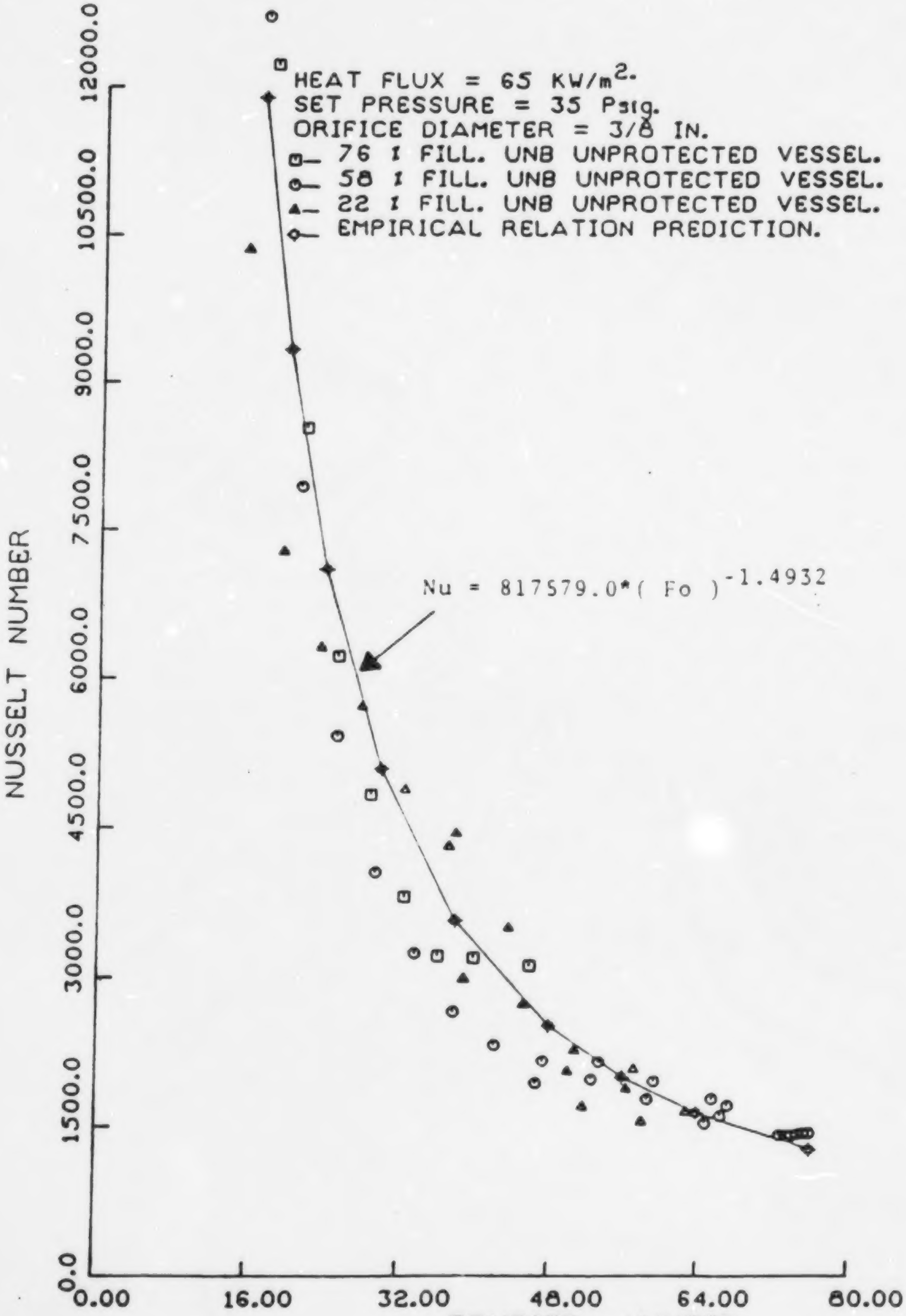


Fig. 4.14 Nusselt number versus Fourier number for the unprotected tank with 3/8 in. orifice diameter.

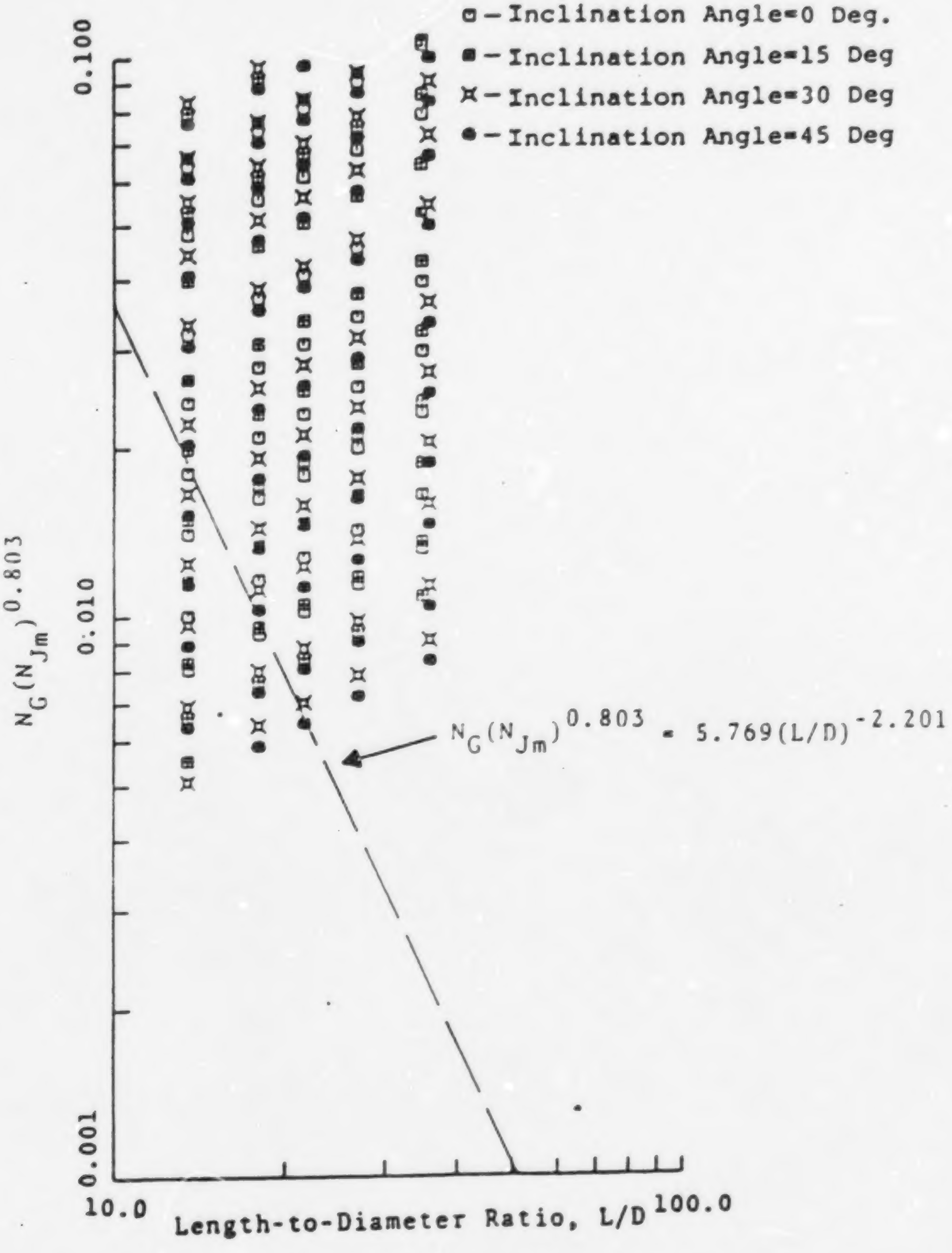


Fig. 5.1 Optimisation of the line diameter for geysering in the UNB tank with Freon-11.

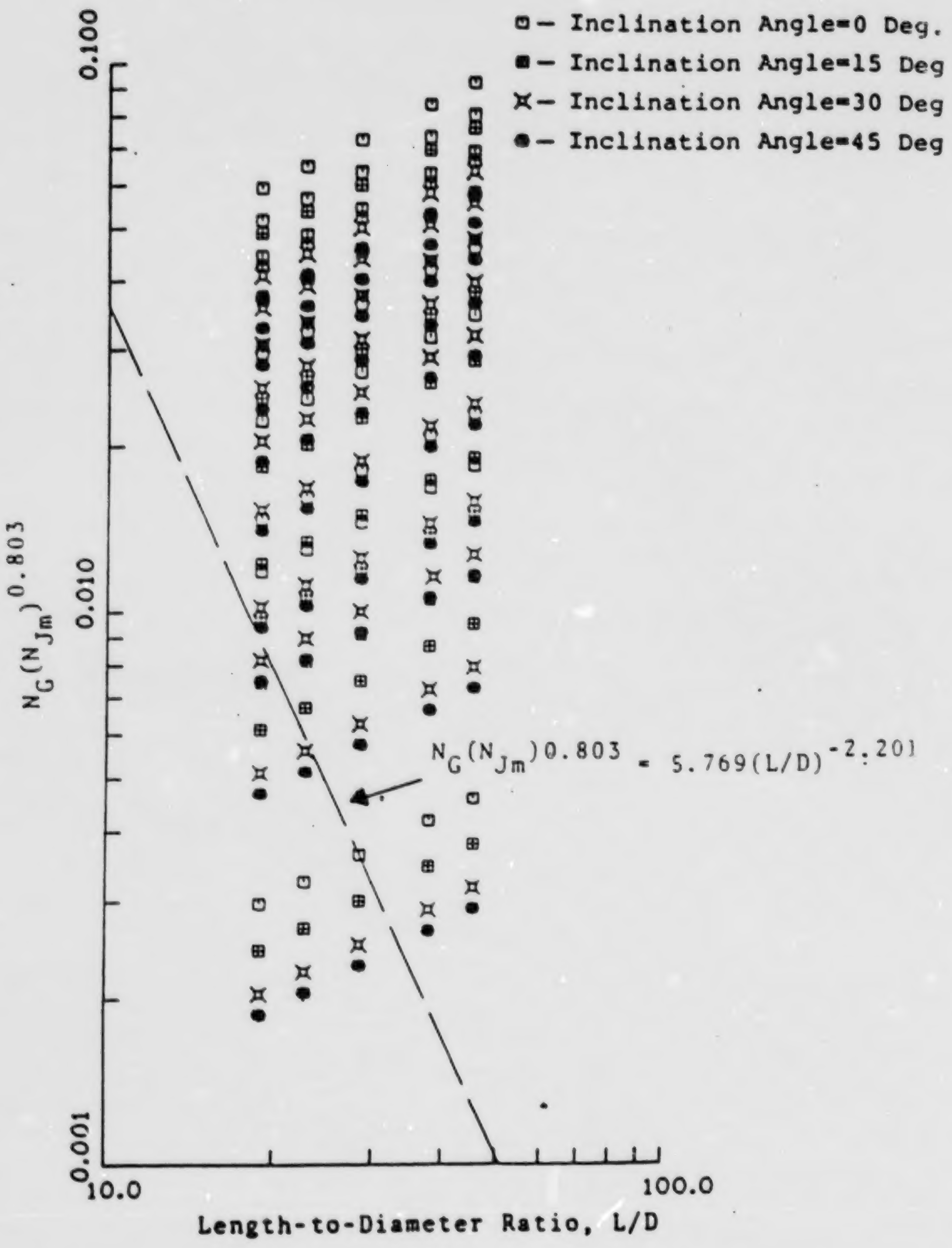


Fig. 5.2 Optimisation of the line diameter for geysering in a rail tank car with propane.

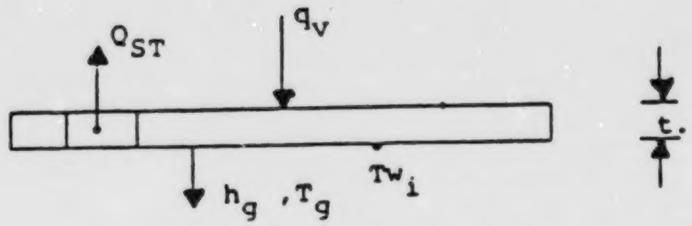


Fig. 5.3(a) Model for the heat transfer in the vapour space without a geyser.

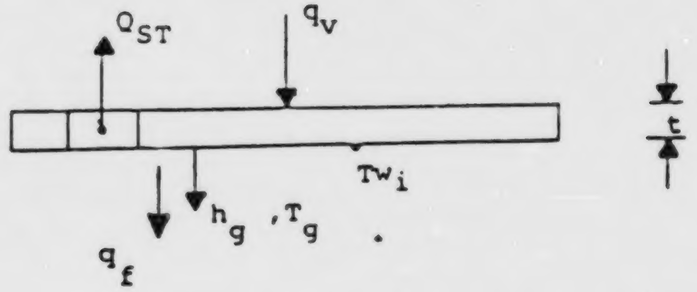


Fig. 5.3(b) Model for the heat transfer in the vapour space with a geyser.

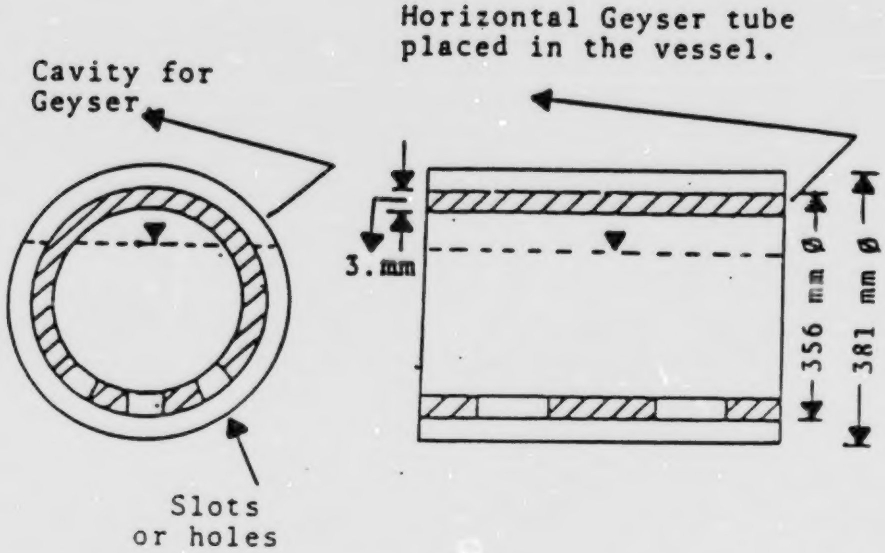
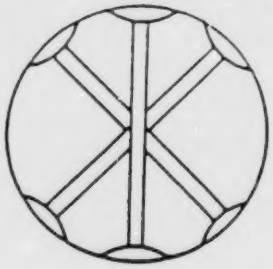


Fig. 5.4 Geyser system I for the UNB tank

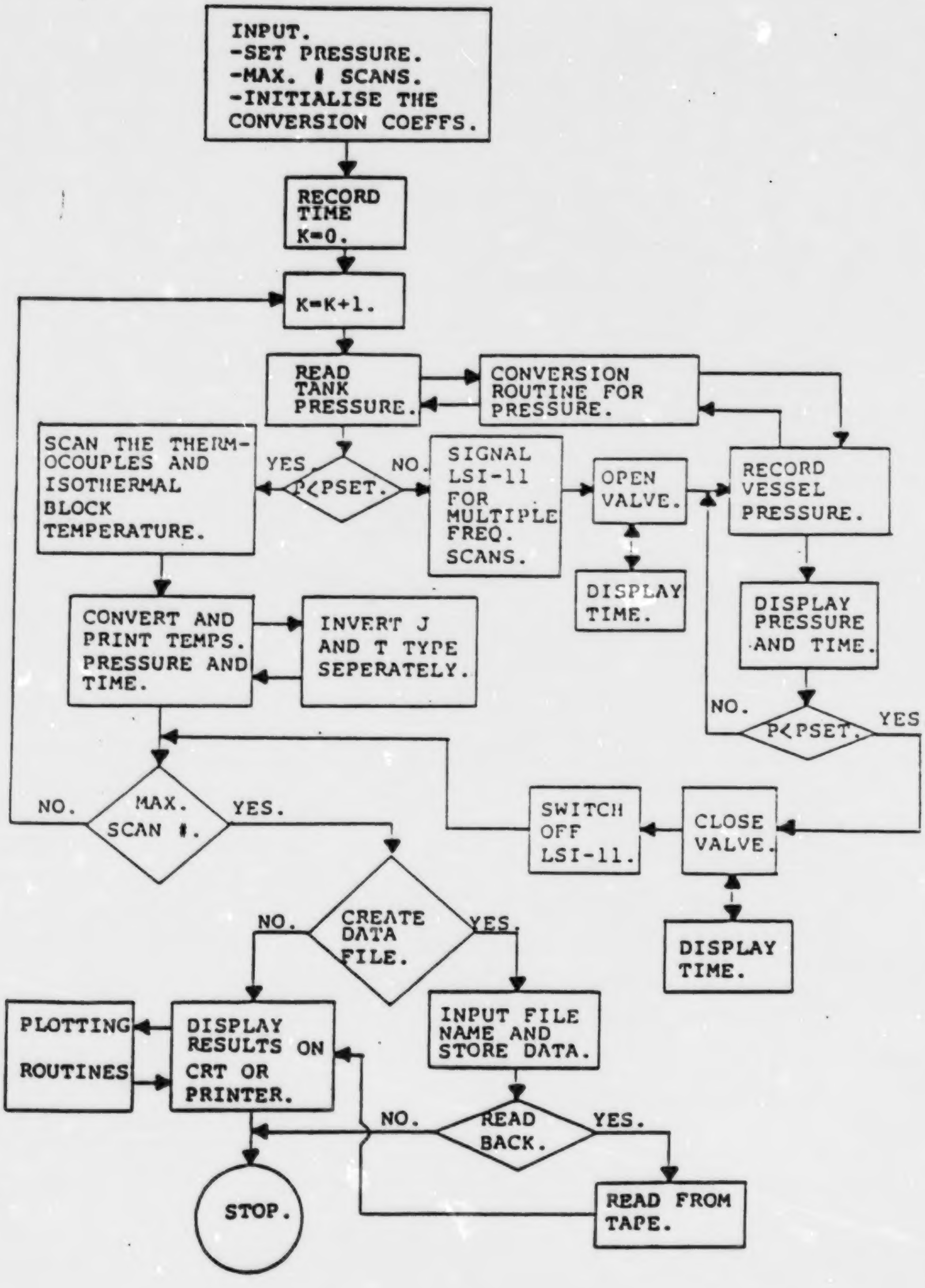


No. of tubes in UNB tank car = 2 of (5/8" Ø x 13.5ft)
No. of tubes in Rail tank car = 30 of (4" Ø x 9.5ft)

Fig. 5.5 Geyser system II for the UNB tank.

APPENDICES

APPENDIX I(a)


INPUT.
-SET PRESSURE.
-MAX. # SCANS.
-INITIALISE THE CONVERSION COEFFS.
RECORD TIME K=0.
K=K+1.
READ TANK PRESSURE.
CONVERSION ROUTINE FOR PRESSURE.
SCAN THE THERMOCOUPLES AND ISOTHERMAL BLOCK TEMPERATURE.
YES
P<PSET.
NO.
SIGNAL LSI-11 FOR MULTIPLE FREQ. SCANS.
OPEN VALVE.
RECORD VESSEL PRESSURE.
DISPLAY TIME.
DISPLAY PRESSURE AND TIME.
CONVERT AND PRINT TEMPS. PRESSURE AND TIME.
INVERT J AND T TYPE SEPERATELY.
NO.
P<PSET.
YES.
NO.
MAX. SCAN #.
YES.
SWITCH OFF LSI-11.
CLOSE VALVE.
DISPLAY TIME.
NO.
CREATE DATA FILE.
YES.
PLOTTING ROUTINES
DISPLAY RESULTS ON CRT OR PRINTER.
INPUT FILE NAME AND STORE DATA.
NO.
READ BACK.
YES.
STOP.
READ FROM TAPE.

Flow diagram for the Experimental scanning program.

APPENDIX I(b)

Listing of the Experimental scanning program.

```
10 CLEAR 709
20 K8=0 @ Z1=0
30 OPTION BASE 1@ CLEAR
40 ! DIM C1(20),C2(7),S1(30,4)
50 ! SHORT P(2,45),T7(30),T9(30
   )
60 MASS STORAGE IS ":D701"
70 OUTPUT 709 ;"AF20AL62S01"
80 GOSUB 1930 @ K=0 @ D=0
90 DISP "ENTER SET PRESSURE"
100 INPUT P
110 DISP "ENTER NO. OF SCANS"
120 INPUT K1@ P1=.95*P @ Q1=TIME
130 CLEAR @ PRINT "START TIME=":
    Q
140 PRINT "SET PRESSURE=";P;"PSI
    G"
150 PRINT "CLOSING PRESSURE=";P1
    ;"PSIG"
160 PRINT "TOTAL # SCANS=";K1
170 PRINT " "
180 DISP "SCANNING.. "
190 K=K+1
200 GOSUB 2480 ! THERM SCAN
210 P(K,45)=TIME-Q1
220 GOSUB 1520 ! CHECK THE VALVE
230 DISP " "
240 DISP "SCAN#";K;"AT";P(K,45);
    "SECS"
250 PRINT "SCAN#";K;"AT";P(K,45)
    ,"SECS"
260 PRINT "PRESS=";P(K,44)
270 DISP "PRESS=";P(K,44)
280 IF K8=1 THEN 300
290 GOSUB 830
300 K8=0
310 IF K<K1 THEN GOTO 190
320 DISP "OUTPUT ON PRINTER? (Y/
    N)"
330 INPUT F$
340 IF F$="N" THEN GOTO 380
350 CRT IS 2
360 GOSUB 2560
370 CRT IS 1
380 DISP "PLEASE WAIT...."
390 FOR K=1 TO K1
400 IF P(K,1)>10 THEN 450
410 DISP " " @ DISP " " @ DISP "
    "
420 DISP "SCAN# ",K
430 DISP " "
440 GOSUB 830
450 NEXT K
460 DISP "STORE DATA..(Y/N)"
479 INPUT C$
480 IF C$="N" THEN GOTO 580
490 CLEAR
500 DISP "ENTER DATA FILE NAME"
510 INPUT A$
520 PRINT "DATA STORED IN ";A$
530 R=8*K1*45
540 CREATE A$,1,R
550 ASSIGN# 1 TO A$
560 PRINT# 1 ; P(,)
570 ASSIGN# 1 TO *
580 GOSUB 3470
590 PRINT "***MASS READINGS***"
600 PRINT "" @ PRINT ""
610 PRINT "PRV#";"    TIME";"
      MASS" @ PRINT " "
620 FOR I=1 TO Z1
630 T9(I)=0
640 FOR J=1 TO 4
650 ! PRINT T7(I);S1(I,J)
660 T9(I)=T9(I)+S1(I,J)
670 NEXT J
680 PRINT I;"  ",T7(I),T9(I)
690 NEXT I
700 GOSUB 2800
710 GOSUB 3670
720 DISP "PLOT TEMP-TIME (Y/N)"
730 INPUT R$
740 IF R$="N" THEN GOTO 810
750 DISP "ENTER THERM NO.  "
760 INPUT Y1
770 GOSUB 3040
780 DISP "MORE PLOT (Y/N)"
790 INPUT R$
800 IF R$="Y" THEN GOTO 750
810 CLEAR @ DISP "NORMAL TERMINA
    TION" @ END
820 ! SUB INVERT
830 R=P(K,20)
840 GOSUB 1090
850 FOR N=1 TO 25
860 IF N=20 THEN 960
870 V=P(K,N)
880 S=V*1000000+R
890 GOSUB 1240
900 P(K,N)=S
910 IF N=3 THEN 960
920 IF N=19 THEN 960
930 IF N=23 THEN 960
940 IF N=25 THEN 960
950 DISP N;P(K,N)
960 NEXT N
970 R=P(K,40)
980 GOSUB 2100
990 FOR N=26 TO 43
1000 IF N=40 THEN 1070
1010 V=P(K,N)
1020 S=V*1000000+R
1030 GOSUB 2250
1040 P(K,N)=S
1050 IF N=39 THEN 1070
1060 DISP N;P(K,N)
1070 NEXT N
1080 RETURN
1090 ! SUB CONVERT R TO MICV
1100 IF R>=2.5 THEN GOTO 1150
```

```
1110 R=2.5-R
1120 R=R/.1
1130 R=25-R ! ITB<25
1140 GOTO 1180
1150 R=R-2.5
1160 R=R/.1
1170 R=25+R ! ITB>25
1180 S1=0
1190 FOR I=8 TO 1 STEP -1
1200 S1=(S1+C1(I))*R
1210 NEXT I
1220 R=S1
1230 RETURN
1240 ! INVERT EMF TO ACTUAL TEMP
1250 IF N=3 THEN 1510
1260 IF N=19 THEN 1510
1270 IF N=23 THEN 1510
1280 IF N=25 THEN 1510
1290 IF N=39 THEN 1510
1300 T1=20
1310 W=0
1320 S1=0
1330 V1=S
1340 FOR I=8 TO 1 STEP -1
1350 S1=(S1+C1(I))*T1
1360 NEXT I
1370 S1=S1-V1
1380 S2=0
1390 FOR I=8 TO 2 STEP -1
1400 S2=(S2+I*C1(I))*T1
1410 NEXT I
1420 S2=S2+C1(1)
1430 N1=T1-S1/S2
1440 E1=ABS(N1-T1)
1450 T1=N1
1460 IF E1<=.002 THEN 1500
1470 W=W+1
1480 IF W>15 THEN 1510
1490 GOTO 1320
1500 S=T1
1510 RETURN
1520 ! SUB VALVE CHECK
1530 OUTPUT 709 ;"AI63"
1540 ENTER 709 ; W
1550 GOSUB 1900 ! CONVERT
1560 P(K,44)=W
1570 IF P(K,44)<P THEN RETURN
1580 GOSUB 1600 ! OPEN VALVE
1590 RETURN
1600 ! OPEN THE VALVE
1610 K8=1
1620 GOSUB 3340
1630 PRINT " "
1640 Q=TIME-Q1
1650 PRINT "VALVE OPENED AT";Q;"
     SECS"
1660 OUTPUT 709 ;"DC4,0" ! VALVE
1670 OUTPUT 709 ;"AI63"
1680 ENTER 709 ; W
1690 GOSUB 1900 ! CONVERT
```

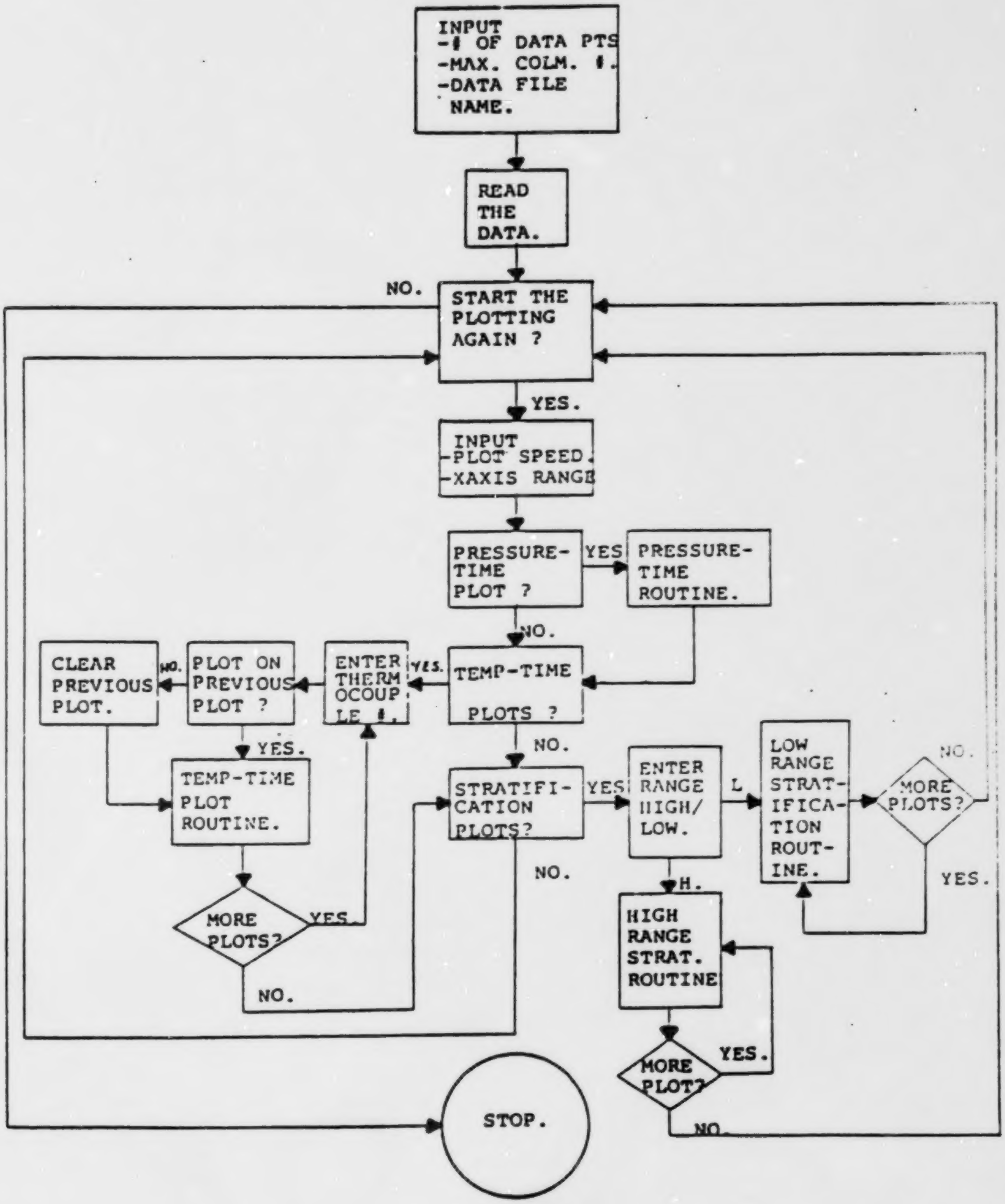
```
1700 PRINT "VESSEL PRESS=";W
1710 K=K+1
1720 IF K>K1 THEN 310
1730 GOSUB 2480 ! SCAN
1740 Q=TIME-Q1
1750 OUTPUT 709 ;"AI63"
1760 ENTER 709 ; W
1770 GOSUB 1900 ! CONVERT
1780 PRINT "VESSEL PRESS=";W
1790 P(K,44)=W
1800 P(K,45)=Q
1810 IF P(K,44)>P(K-1,44) THEN G
     OSUB 3340
1820 IF W<P1 THEN 1840
1830 GOTO 1710
1840 OUTPUT 709 ;"DO4,0" ! CLOSE
      VALVE
1850 Q=TIME-Q1
1860 PRINT "VALVE CLOSED AT",Q,"
     SECS"
1870 PRINT "   "
1880 GOSUB 3340
1890 RETURN
1900 ! EMF TO PRESS (VESSEL)
1910 W=4296.702*(W-.038834)
1920 RETURN
1930 ! SUB COEFF
1940 C1(1)=38.74077384
1950 C1(2)=.033190198092
1960 C1(3)=2.0714183645E-4
1970 C1(4)=-2.1945834823E-6
1980 C1(5)=1.103190055E-8
1990 C1(6)=-3.0927581898E-11
2000 C1(7)=4.5653337165E-14
2010 C1(8)=-2.761687804E-17
2020 C2(1)=50.372753027
2030 C2(2)=.030425491284
2040 C2(3)=-8.5669750464E-5
2050 C2(4)=1.3348825735E-7
2060 C2(5)=-1.7022405966E-10
2070 C2(6)=1.9416091001E-13
2080 C2(7)=-9.6391844859E-17
2090 RETURN
2100 ! SUB CONVERT R TO MICV
2110 IF R>=2.5 THEN GOTO 2160
2120 R=2.5-R
2130 R=R/.1
2140 R=25-R ! ITB<25
2150 GOTO 2190
2160 R=R-2.5
2170 R=R/.1
2180 R=25+R ! ITB>25
2190 S1=0
2200 FOR I=7 TO 1 STEP -1
2210 S1=(S1+C2(I))*R
2220 NEXT I
2230 R=S1
2240 RETURN
2250 ! INVERT EMF TO ACTUAL TEMP
2260 T1=20
```

```
2270 W=0
2280 S1=0
2290 V1=S
2300 FOR I=7 TO 1 STEP -1
2310 S1=(S1+C2(I))*T1
2320 NEXT I
2330 S1=S1-V1
2340 S2=0
2350 FOR I=7 TO 2 STEP -1
2360 S2=(S2+I*C2(I))*T1
2370 NEXT I
2380 S2=S2+C2(1)
2390 N1=T1-S1/S2
2400 E1=ABS(N1-T1)
2410 T1=N1
2420 IF E1<=.002 THEN 2460
2430 W=W+1
2440 IF W>30 THEN 2470
2450 GOTO 2280
2460 S=T1
2470 RETURN
2480 ! SUBROUTINE SCAN
2490 ! WAIT 3000
2500 FOR J=1 TO 43
2510 ! WAIT 500
2520 OUTPUT 709 ;"ASVT3"
2530 ENTER 709 ; P(K,J)
2540 NEXT J
2550 RETURN
2560 ! SUB OUTPUT
2570 FOR I=1 TO K1
2580 DISP " "
2590 DISP "SCAN#";I;"AT";P(I,45)
     ;"SECS"
2600 DISP "PRESS=";P(I,44);"PSIG
     "
2610 FOR J=1 TO 43
2620 DISP J;P(I,J)
2630 NEXT J
2640 NEXT I
2650 RETURN
2660 ! SUB SCALE PRESSURE
2670 GCLEAR
2680 SCALE -15,80,-10,50
2690 XAXIS 0,10,0,80
2700 YAXIS 0,10,0,45
2710 LDIR 0 @ MOVE 40,-10 @ LABE
     L "MINS" @ LDIR 90 @ MOVE -
     10,35
2720 LABEL "PSIG" @ LDIR 0
2730 MOVE 7,-5 @ LABEL "10" @ MO
     VE 17,-5 @ LABEL "20"
2740 MOVE 27,-5 @ LABEL "30"
2750 MOVE 37,-5 @ LABEL "40"
2760 MOVE 47,-5 @ LABEL "50" @ M
     OVE 57,-5 @ LABEL "60" @ MO
     VE 67,-5 @ LABEL "70"
2770 MOVE -7,9 @ LABEL "10"
2780 MOVE -7,19 @ LABEL "20" @ M
     OVE -7,29 @ LABEL "30" @ MO
     VE -7,39 @ LABEL "40"
```

```
2790 RETURN
2800 ! SUB PLOT
2810 GOSUB 2660
2820 FOR I=1 TO K1
2830 P(I,45)=P(I,45)/60
2840 PLOT P(I,45),P(I,44)
2850 NEXT I @ COPY @ RETURN
2860 ! SUB SCALE TEMP
2870 PRINT " " @ PRINT " "
2880 PRINT "THERMC.# ";Y1
2890 GCLEAR
2900 SCALE -8.5,80,-32,200
2910 XAXIS 0,10,0,80
2920 YAXIS 0,20,0,170
2930 LDIR 0 @ MOVE 40,-32 @ LABE
     L "MINS"
2940 LDIR 0 @ MOVE -3,175 @ LABE
     L "TEMP(C)"
2950 LDIR 0 @ MOVE 7,-18 @ LABEL
      "10" @ MOVE 17,-18 @ LABEL
      "20" @ MOVE 27,-18 @ LABEL
      "30"
2960 MOVE 37,-18 @ LABEL "40"
2970 MOVE 47,-18 @ LABEL "50" @
     MOVE 57,-18 @ LABEL "60" @
     MOVE 67,-18 @ LABEL "70"
2980 LDIR 0
2990 MOVE -6,35 @ LABEL "40"
3000 MOVE -6,75 @ LABEL "80"
3010 MOVE -8.5,115 @ LABEL "120"
3020 MOVE -8.5,155 @ LABEL "160"
3030 RETURN
3040 ! THERM. PLOT
3050 IF P(K1,Y1)<170 THEN 3080
3060 GOSUB 3130
3070 GOTO 3090
3080 GOSUB 2860
3090 FOR I=1 TO K1
3100 PLOT P(I,45),P(I,Y1)
3110 NEXT I @ COPY
3120 RETURN
3130 ! SUB SCALE TEMP(HIGH)
3140 PRINT " " @ PRINT " "
3150 PRINT "THERMC.# ";Y1
3160 GCLEAR
3170 SCALE -8.5,80,-32,320
3180 XAXIS 0,10,0,80
3190 YAXIS 0,20,0,300
3200 LDIR 0 @ MOVE 40,-32 @ LABE
     L "MINS"
3210 LDIR 0 @ MOVE -3,305 @ LABE
     L "TEMP(C)"
3220 LDIR 0 @ MOVE 7,-18 @ LABEL
      "10" @ MOVE 17,-18 @ LABEL
      "20" @ MOVE 27,-18 @ LABEL
      "30"
3230 MOVE 37,-18 @ LABEL "40"
3240 MOVE 47,-18 @ LABEL "50" @
     MOVE 57,-18 @ LABEL "60" @
     MOVE 67,-18 @ LABEL "70"
```

```
3250 LDIR 0
3260 MOVE -6,35 @ LABEL "40"
3270 MOVE -6,75 @ LABEL "80"
3280 MOVE -8.5,115 @ LABEL "120"
3290 MOVE -6.5,155 @ LABEL "160"
3300 MOVE -8.5,195 @ LABEL "200"
3310 MOVE -8.5,235 @ LABEL "240"
3320 MOVE -8.5,275 @ LABEL "280"
3330 RETURN
3340 ! FREQUENCY SCAN
3350 Z1=Z1+1 @ Q4=TIME-Q1
3360 OUTPUT 709 ;"DC4,14CT0,1CF0
     ,3CR0,2D04,14"
3370 ENTER 709 ; S1(Z1,1)
3380 OUTPUT 709 ;"DC4,15CT0,1CF0
     ,3CR0,2D04,15"
3390 ENTER 709 ; S1(Z1,2)
3400 OUTPUT 709 ;"DC4,13CT0,1CF0
     ,3CR0,2D04,13"
3410 ENTER 709 ; S1(Z1,3)
3420 OUTPUT 709 ;"DC4,12CT0,1CF0
     ,3CR0,2D04,12"
3430 ENTER 709 ; S1(Z1,4)
3440 Q5=TIME-Q1
3450 T7(Z1)=Q4+(Q5-Q4)/2
3460 RETURN
3470 ! FREQUENCY-MASS CONV
3480 FOR I=1 TO Z1
3490 FOR J=1 TO 4
3500 X1=1/S1(I,J)
3510 GOSUB 3550
3520 S1(I,J)=M
3530 NEXT J @ NEXT I
3540 GOSUB 3550
3550 ! SUB FREQ. CALIB.
3560 IF J<>1 THEN GOTO 3590
3570 M=-140.367+.009*X1
3580 GOTO 3660
3590 IF J<>2 THEN 3620
3600 M=-139.464+.009*X1
3610 GOTO 3660
3620 IF J<>3 THEN 3650
3630 M=-144.915+.01*X1
3640 GOTO 3660
3650 M=-137.668+.011*X1
3660 RETURN
3670 ! MASS PLOT
3680 GOSUB 3720 ! MASS SCALE
3690 FOR I=1 TO Z1
3700 PLOT P(I,45),T9(I) @ NEXT I
3710 RETURN
3720 ! SUBSCALE MASS
3730 GCLEAR @ SCALE -5,30,450,75
     0
3740 XAXIS 500,5,0,30 @ YAXIS 0,
     50,500,700
3750 LDIR 0 @ MOVE 25,510 @ LABE
     L "MINS" @ MOVE 10,710 @ LA
     BEL "MASS(LBS)" @ LDIR 0
3760 MOVE 5,480 @ LABEL "5" @ MO
     VE 9,480 @ LABEL "10"
3770 MOVE 14,480 @ LABEL "15"
3780 MOVE 19,430 @ LABEL "20"
3790 MOVE 24,480 @ LABEL "25"
3800 MOVE -4,495 @ LABEL "500"
3810 MOVE -4,545 @ LABEL "550"
3820 MOVE -4,590 @ LABEL "600"
3830 MOVE -4,640 @ LABEL "650"
3840 MOVE -4,690 @ LABEL "700"
3850 RETURN
```

APPENDIX II(a)



Flow diagram for the Plotting program.

APPENDIX II(b)

Listing of the Plotting program.

```
10 OPTION BASE 1@ CLEAR
20 ! SHORT P(60,45)
30 DISP "ENTER # DATA PTS."
40 INPUT K1
50 Z1=0
60 CLEAR
70 DISP "ENTER MAX.COLUMN #"
80 INPUT C2
90 C1=C2-1
100 CLEAR
110 MASS STORAGE IS ":D701"
120 DISP "ENTER DATA FILE NAME"
130 INPUT B$
140 ASSIGN# 1 TO B$
150 READ# 1 ; P(,)
160 FOR I=1 TO K1
170 P(I,C2)=P(I,C2)/60 @ NEXT I
180 CLEAR
190 DISP "ENTER PLOT SPEED"
200 INPUT W1
210 CLEAR
220 DISP "ENTER XAXIS RANGE"
230 DISP " 1 FOR (0-25)"
240 DISP " 0 FOR (0-75)"
250 INPUT S1
260 CLEAR
270 DISP "PLOT PRESS-TIME ?"
280 INPUT D$
290 IF D$="N" THEN 310
300 GOSUB 770
310 CLEAR
320 DISP "PLOT TEMP-TIME (Y/N)"
330 INPUT R$
340 IF R$="N" THEN GOTO 500
350 Z1=1
360 DISP "ENTER THERM. NO..  "
370 INPUT Y1
380 DISP "ENTER AGAIN TO BE STOR
    ED IN STRING"
390 INPUT A$
400 DISP "PLOT ON PREVIOUS GRAPH
    ?"
410 INPUT H$
420 IF H$="Y" THEN GOTO 450
430 GCLEAR
440 Z1=0
450 PENUP
460 GOSUB 1020
470 DISP "MORE TEMP PLOT. (Y/N)"
480 INPUT R$
490 IF R$="Y" THEN GOTO 350
500 DISP "STRATIFICATION PLOTS?"
510 INPUT S$
520 IF S$="N" THEN GOTO 570
530 DISP "HIGH OR LOW RANGE (H/L
    )"
540 INPUT R$
550 IF R$="H" THEN GOSUB 1860
560 IF R$="L" THEN GOSUB 2460
570 CLEAR @ DISP "START PLOTTING
     AGAIN ?"
580 INPUT H$
590 IF H$="N" THEN 610
600 GOTO 190
610 ASSIGN# 1 TO *
620 END
630 ! SUB SCALE PRESSURE
640 GCLEAR
650 SCALE -1,16,-10,50
660 XAXIS 0,3,0,15
670 YAXIS 0,10,0,45
680 LDIR 0 @ MOVE 10,-10 @ LABEL
     "MINS" @ LDIR 0 @ MOVE 1,45
690 LABEL "PSIG" @ LDIR 0
700 MOVE 3,-5 @ LABEL "3" @ MOVE
     6,-5 @ LABEL "6"
710 MOVE 9,-5 @ LABEL "9"
720 MOVE 12,-5 @ LABEL "12"
730 MOVE 14.5,-5 @ LABEL "15"
740 MOVE -1,9 @ LABEL "10"
750 MOVE -1,19 @ LABEL "20" @ MO
    VE -1,29 @ LABEL "30" @ MOVE
     -1,39 @ LABEL "40"
760 RETURN
770 ! SUB PLOT
780 IF S1=0 THEN GOSUB 1330
790 IF S1=0 THEN GOTO 810
800 GOSUB 630
810 FOR I=1 TO K1
820 PLOT P(I,C2),P(I,C1)
830 WAIT W1
840 NEXT I @ RETURN
850 ! SUB SCALE TEMP
860 IF Z1=1 THEN 1000
870 SCALE -2,16,-32,200
880 XAXIS 0,3,0,15
890 YAXIS 0,40,0,170
900 LDIR 0 @ MOVE 10,-32 @ LABEL
     "MINS"
910 LDIR 0 @ MOVE 1,175 @ LABEL
    "TEMP(C)"
920 LDIR 0 @ MOVE 3,-18 @ LABEL
    "3" @ MOVE 6,-18 @ LABEL "6"
     @ MOVE 9,-18 @ LABEL "9"
930 MOVE 12,-18 @ LABEL "12"
940 MOVE 14.5,-18 @ LABEL "15"
950 LDIR 0
960 MOVE -1.1,35 @ LABEL "40"
970 MOVE -1.1,75 @ LABEL "80"
980 MOVE -1.6,115 @ LABEL "120"
990 MOVE -1.6,155 @ LABEL "160"
1000 MOVE 10,25 @ LABEL "No.";A$
1010 RETURN
1020 ! THERM. PLOT
1030 IF P(K1,Y1)<170 THEN 1080
1040 IF S1=0 THEN GOSUB 1650
1050 IF S1=0 THEN GOTO 1110
1060 GOSUB 1160
1070 GOTO 1110
1080 IF S1=0 THEN GOSUB 1470
1090 IF S1=0 THEN GOTO 1110
```

```
1100 GOSUB 350
1110 FOR I=1 TO K1
1120 PLOT P(I,C2),P(I,Y1)
1130 WAIT W1
1140 NEXT I
1150 RETURN
1160 ! SUB SCALE TEMP(HIGH)
1170 IF Z1=1 THEN 1310
1180 SCALE -2,16,-90,550
1190 XAXIS 0,3,0,15
1200 YAXIS 0,100,0,500
1210 LDIR 0 @ MOVE 13,-80 @ LABE
     L "MINS"
1220 LDIR 0 @ MOVE 1,550 @ LABEL
      "TEMP(C)"
1230 LDIR 0 @ MOVE 3,-45 @ LABEL
      "3" @ MOVE 6,-45 @ LABEL "
     6" @ MOVE 9,-45 @ LABEL "9"
1240 MOVE 12,-45 @ LABEL "12"
1250 MOVE 14.5,-45 @ LABEL "15"
1260 LDIR 0
1270 MOVE -1.7,95 @ LABEL "100"
1280 MOVE -1.7,195 @ LABEL "200"
1290 MOVE -1.7,295 @ LABEL "300"
1300 MOVE -1.7,395 @ LABEL "400"
1310 MOVE 10,60 @ LABEL "No.";A$
1320 RETURN
1330 ! PRESS SCALE(0-70)
1340 GCLEAR
1350 SCALE -15,80,-10,50
1360 XAXIS 0,10,0,80
1370 YAXIS 0,10,0,45
1380 LDIR 0 @ MOVE 40,-10 @ LABE
     L "MINS" @ LDIR 90 @ MOVE -
     10,35
1390 LABEL "PSIG" @ LDIR 0
1400 MOVE 7,-5 @ LABEL "10" @ MO
     VE 17,-5 @ LABEL "20"
1410 MOVE 27,-5 @ LABEL "30"
1420 MOVE 37,-5 @ LABEL "40"
1430 MOVE 47,-5 @ LABEL "50" @ M
     OVE 57,-5 @ LABEL "60" @ MO
     VE 67,-5 @ LABEL "70"
1440 MOVE -7,9 @ LABEL "10"
1450 MOVE -7,19 @ LABEL "20" @ M
     OVE -7,29 @ LABEL "30" @ MO
     VE -7,39 @ LABEL "40"
1460 RETURN
1470 ! SCALE TEMP(0-70)
1480 IF Z1=1 THEN 1630
1490 SCALE -8.5,80,-32,200
1500 XAXIS 0,10,0,75
1510 YAXIS 0,20,0,170
1520 LDIR 0 @ MOVE 61,-32 @ LABE
     L "MINS"
1530 MOVE 5,175 @ LABEL "TEMP(C)
     "
1540 MOVE 7,-18 @ LABEL "10" @ M
     OVE 17,-18 @ LABEL "20" @ M
     OVE 27,-18 @ LABEL "30"
```

```
1550 MOVE 37,-18 @ LABEL "40"
1560 MOVE 47,-18 @ LABEL "50" @
     MOVE 57,-18 @ LABEL "60" @
     MOVE 67,-18 @ LABEL "70"
1570 MOVE -6.35 @ LABEL "40"
1580 MOVE -6,75 @ LABEL "80"
1590 MOVE -8.5,115 @ LABEL "120"
1600 MOVE -8.5,155 @ LABEL "160"
1610 MOVE -.5,166 @ LABEL "^"
1620 MOVE 74.5,-5 @ LABEL ">"
1630 MOVE 45,25 @ LABEL "No.";A$
1640 RETURN
1650 ! SCALE TEMP(HIGH,0-70)
1660 IF Z1=1 THEN 1830
1670 SCALE -15,80,-45,320
1680 XAXIS 0,10,0,75
1690 YAXIS 0,50,0,298
1700 MOVE 61,-45 @ LABEL "MINS"
1710 MOVE 5,290 @ LABEL "TEMP(C)
     "
1720 MOVE 7,-25 @ LABEL "10" @ M
     OVE 17,-25 @ LABEL "20" @ M
     OVE 27,-25 @ LABEL "30"
1730 MOVE 37,-25 @ LABEL "40"
1740 MOVE 47,-25 @ LABEL "50" @
     MOVE 57,-25 @ LABEL "60" @
     MOVE 67,-25 @ LABEL "70"
1750 MOVE -7.5,44 @ LABEL "50"
1760 MOVE -10,94 @ LABEL "100"
1770 MOVE -10,144 @ LABEL "150"
1780 MOVE -10,194 @ LABEL "200"
1790 MOVE -10,244 @ LABEL "250"
1800 MOVE -10;294 @ LABEL "300"
1810 MOVE -1,292 @ LABEL "^"
1820 MOVE 74.5,-6 @ LABEL ">"
1830 MOVE 45,40 @ LABEL "No.";A$
1840 RETURN
1850 ! STRATIFICATION (HIGH RANG
     E"
1860 DISP "ENTER M1,M2"
1870 INPUT M1,M2
1880 DISP "ENTER STEP No."
1890 INPUT S1
1900 GOSUB 2220
1910 FOR K=M1 TO M2 STEP S1
1920 PLOT P(K,26),0
1930 PLOT P(K,11),2.55
1940 PLOT P(K,14),6.685
1950 PLOT P(K,13),10.765
1960 PLOT P(K,16),14.33
1970 PLOT P(K,10),15.33
1980 PLOT P(K,15),17.41
1990 PLOT P(K,22),19.38
2000 PLOT P(K,17),21.465
2010 PENUP
2020 ! PLOT P(K,19),23.605
2030 PLOT P(K,18),24.585
2040 PLOT P(K,21),25.45
2050 PLOT P(K,9),26.59
2060 PLOT P(K,7),27.51
```

```
2070 PLOT P(K,2),29.63
2080 PLOT P(K,4),30.49
2090 PLOT P(K,6),31.55
2100 PLOT P(K,1),32.46
2110 ! PLOT P(K,3),33.375
2120 PLOT P(K,8),34.65
2130 PLOT P(K,5),35.625
2140 WAIT 3000
2150 PENUP
2160 NEXT K
2170 PENUP
2180 DISP "PLOT AGAIN ?"
2190 INPUT A$
2200 IF A$="Y" THEN GOTO 1860
2210 RETURN
2220 ! SUBSCALE
2230 GCLEAR
2240 SCALE 40,110,-8,40
2250 XAXIS 0,10,50,100
2260 YAXIS 50,5,0,38
2270 LDIR 0
2280 MOVE 90,-6
2290 LABEL "TEMP"
2300 MOVE 55,33
2310 LABEL "HEIGHT"
2320 MOVE 58,-3 @ LABEL "60"
2330 MOVE 68,-3 @ LABEL "70"
2340 MOVE 78,-3 @ LABEL "30"
2350 MOVE 88,-3 @ LABEL "90"
2360 MOVE 98,-3 @ LABEL "100"
2370 MOVE 45,4 @ LABEL "5"
2380 MOVE 44,9 @ LABEL "10"
2390 MOVE 44,14 @ LABEL "15"
2400 MOVE 44,19 @ LABEL "20"
2410 MOVE 44,24 @ LABEL "25"
2420 MOVE 44,29 @ LABEL "30"
2430 MOVE 44,34 @ LABEL "35"
2440 MOVE 37,34 @ LABEL "35"
2450 RETURN
2460 ! STRATIFICATION (LOW RANGE
"
2470 DISP "ENTER M1,M2"
2480 INPUT M1,M2
2490 DISP "ENTER STEP No."
2500 INPUT S1
2510 GOSUB 2830
2520 FOR K=M1 TO M2 STEP S1
2530 PLOT P(K,26),0
2540 PLOT P(K,11),2.55
2550 PLOT P(K,14),6.685
2560 PLOT P(K,13),10.765
2570 PLOT P(K,16),14.33
2580 PLOT P(K,10),15.33
2590 PLOT P(K,15),17.41
2600 PLOT P(K,22),19.38
2610 PLOT P(K,17),21.465
2620 PENUP
2630 ! PLOT P(K,19),23.605
2640 PLOT P(K,18),24.585
2650 PLOT P(K,21),25.45
```

```
2660 PLOT P(K,9),26.59
2670 PLOT P(K,7),27.51
2680 PLOT P(K,2),29.63
2690 PLOT P(K,4),30.49
2700 PLOT P(K,6),31.55
2710 PLOT P(K,1),32.46
2720 ! PLOT P(K,3),33.375
2730 PLOT P(K,8),34.65
2740 PLOT P(K,5),35.625
2750 WAIT 3000
2760 PENUP
2770 NEXT K
2780 PENUP
2790 DISP "PLOT AGAIN ?"
2800 INPUT A$
2810 IF A$="Y" THEN GOTO 2470
2820 RETURN
2830 ! SUBSCALE
2840 GCLEAR
2850 SCALE 17,52,-8,40
2860 XAXIS 0,5,20,50
2870 YAXIS 20,5,0,38
2880 LDIR 0
2890 MOVE 40,-6
2900 LABEL "TEMP"
2910 MOVE 22,38
2920 LABEL "HEIGHT"
2930 MOVE 24,-3 @ LABEL "25"
2940 MOVE 29,-3 @ LABEL "30"
2950 MOVE 34,-3 @ LABEL "35"
2960 MOVE 39,-3 @ LABEL "40"
2970 MOVE 44,-3 @ LABEL "45"
2980 MOVE 49,-3 @ LABEL "50"
2990 MOVE 18,4 @ LABEL "5"
3000 MOVE 18,9 @ LABEL "10"
3010 MOVE 18,14 @ LABEL "15"
3020 MOVE 18,19 @ LABEL "20"
3030 MOVE 18,24 @ LABEL "25"
3040 MOVE 18,29 @ LABEL "30"
3050 MOVE 18,34 @ LABEL "35"
3060 RETURN
```

APPENDIX III

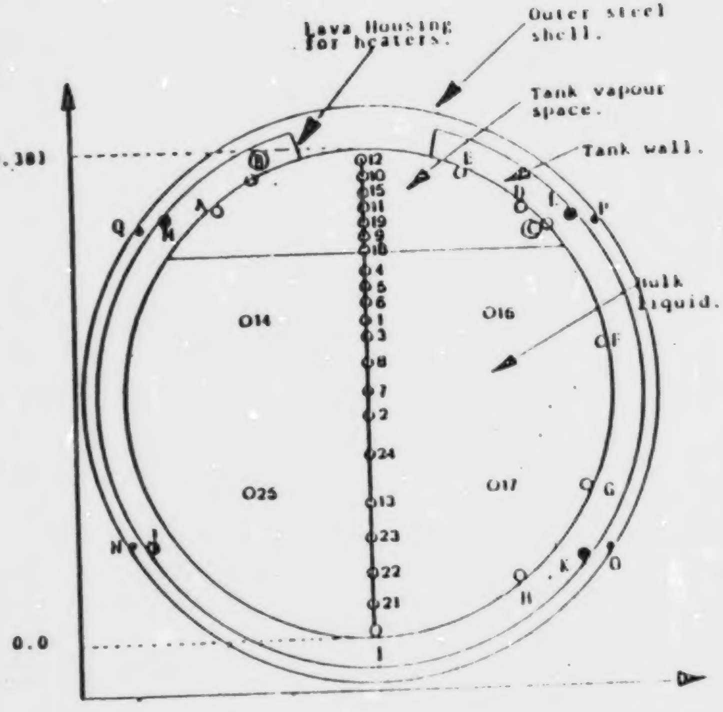
Thermocouples Layout and Experimental Data

+

Sample calculations.

Table III.A Catalogue of the Experimental program.

Type Unprotected or Protected	Q_{IN} KW/m^2.	PRV orifice dia. (in.)	Percent fill	File name on the disc
Unprotected	65	1/4	76	TEST13
"	"	"	58	TEST14
"	"	"	23	TEST15
"	"	3/8	76	FEB1
"	"	"	58	TEST18
"	"	"	23	FEB20
Explosafe	40	"	74	UNBT26
"	"	"	58	UNBT27
"	"	"	23	UNBT28



SYMBOL	Thermocouple #.	Angle(Deg)
A	26	310
B	34	20
C	27	56
D & E	28 & 29	48 & 25
F & G	38 & 35	78 & 110
H & I	37 & 36	142 & 180
J & K	30 & 31	133 & 220
L & M	32 & 33	50 & 300
N & O	42 & 43	140 & 230
P & Q	39 & 41	60 & 310

○ Circled thermocouples are inserted inside the vapour space wall.

Number 44 represents pressure(vessel) in psig.
Number 45 represents time in seconds.
Reference upper diameter - 45.47 cms.

Thermocouple numbers.	Height (cm)	Angle with the vertical (Deg.)	Doubtful or faulty Thermocouple.
12	42.57	-	-
10	41.545	-	-
15	40.495	-	-
11	39.475	-	-
19	38.55	-	YES.
09	37.575	-	-
18	36.595	-	-
04	34.62	-	-
05	33.59	-	-
06	32.60	-	-
01	31.16	-	-
03	30.63	-	YES.
08	29.61	-	-
07	27.635	-	-
02	24.72	-	-
24	22.87	-	-
13	21.83	-	-
23	17.82	-	-
22	14.38	-	-
21	10.34	-	-
36	07.63	180	-
26	-	310	-
27 & 28	-	56 & 48	-
29 & 38	-	25 & 78	-
35 & 37	-	110 & 142	-
30 & 31	-	133 & 220	-
33 & 34	-	300 & 20	YES.
32 & 39	-	50 & 60	-
41 & 42	-	310 & 140	-
43	-	230	-
14	31.2	-	-
16	31.2	-	-
25	22.8	-	-
17	22.8	-	-
20 & 40	Reference Temperature	-	-

Fig. III.A A grid layout of thermocouples along with their locations for an unprotected vessel(UNB) with the PRV orifice of 1/4 in. (Valid for 76, 58 and 23 percent liquid full cases)

RUN NUMBER 1

Q_{IN} = 65 KW/m^2,   Set pressure of the PRV = 35 psig.

Liquid Level = 76% (58.9 deg. with the vertical)

PRV orifice diameter = 1/4 in.

No internal protection.

```
SCAN # 1    SCAN # 2    SCAN # 3    SCAN # 4    SCAN # 5    SCAN # 6    SCAN # 7    SCAN # 8    SCAN # 9    SCAN # 10

 1 21.842    1 21.846    1 22.644    1 24.423    1 27.448    1 30.357    1 34.091    1 38.112    1 42.025    1 44.426
 2 21.867    2 21.846    2 22.248    2 24.079    2 26.958    2 29.335    2 33.688    2 37.585    2 41.455    2 43.784
 3 122130    3 14428     3 33339     3 32030     3 -69037    3 -26779    3 -67718    3 -64409    3 -101060   3 -60565
 4 21.832    4 21.921    4 22.817    4 24.497    4 27.643    4 30.867    4 34.573    4 38.638    4 42.429    4 47.319
 5 21.867    5 21.671    5 22.767    5 24.276    5 27.374    5 30.551    5 34.212    5 38.303    5 42.073    5 46.664
 6 21.812    6 21.846    6 22.668    6 24.251    6 27.472    6 30.43     6 34.212    6 38.207    6 42.168    6 46.445
 7 21.867    7 21.871    7 22.396    7 24.497    7 27.35     7 30.187    7 34.819    7 38.064    7 42.476    7 46.073
 8 21.867    8 21.871    8 22.644    8 24.448    8 27.374    8 30.381    8 34.308    8 38.255    8 42.571    8 46.379
 9 21.867    9 22.217    9 23.434    9 25.898    9 28.913    9 32.226    9 36.866    9 40.332    9 45.007    9 49.942
10  21.842  10  22.168  10  23.236  10  25.751  10  29.936  10  34.642  10  39.394  10  44.861  10  51.058  10  57.571
11  21.842  11  22.193  11  23.335  11  25.751  11  28.62   11  31.652  11  35.464  11  39.736  11  45.149  11  50.619
12  21.842  12  22.193  12  23.286  12  26.266  12  31.079  12  35.99   12  41.514  12  47.262  12  54.079  12  61.058
13  21.816  13  21.822  13  22.149  13  23.783  13  26.37   13  28.725  13  33.028  13  35.905  13  38.69   13  43.734
14  21.842  14  21.871  14  22.347  14  23.684  14  26.615  14  29.432  14  32.569  14  37.225  14  41.455  14  46.849
15  21.842  15  22.217  15  23.286  15  25.751  15  28.869  15  33.508  15  38.104  15  43.159  15  48.674  15  54.602
16  21.867  16  21.871  16  22.347  16  24.645  16  26.542  16  29.296  16  33.246  16  37.225  16  41.431  16  46.52
17  21.842  17  21.846  17  22.174  17  23.857  17  25.904  17  28.993  17  32.302  17  36.17   17  40.17   17  43.976
18  21.892  18  22.316  18  23.403  18  25.947  18  28.596  18  31.474  18  34.959  18  38.829  18  42.903  18  47.601
19  864.73  19  888.9   19  929.14  19  1036.3  19  1155.3  19  1277.8  19  1441    19  1632.3  19  1821.5  19  2028.7
20  2.4003  20  2.4007  20  2.4813  20  2.4817  20  2.4823  20  2.483   20  2.4834  20  2.4842  20  2.4847  20  2.4852
21  22.288  21  22.292  21  22.989  21  24.202  21  25.634  21  29.359  21  31.987  21  35.424  21  38.81   21  43.026
22  22.337  22  22.341  22  22.792  22  23.832  22  26.174  22  29.31   22  32.326  22  35.183  22  39.168  22  43.002
23  22.362  23  22.366  23  22.792  23  24.079  23  25.679  23  29.529  23  32.641  23  35.328  23  39.649  23  43.002
24  22.386  24  22.39   24  22.817  24  24.915  24  27.57   24  29.749  24  34.381  24  38.375  24  40.361  24  44.611
25  22.362  25  22.366  25  22.633  25  24.448  25  27.355  25  30.162  25  33.463  25  37.173  25  40.227  25  44.694
26  22.335  26  23.369  26  27.641  26  34.664  26  43.867  26  54.783  26  67.111  26  79.627  26  92.907  26  106.39
27  22.414  27  24.453  27  29.819  27  36.521  27  44.551  27  53.236  27  62.753  27  71.626  27  80.152  27  87.424
28  22.434  28  24.047  28  29.376  28  37.133  28  46.737  28  57.817  28  70.064  28  82.782  28  95.545  28  187.47
29  22.007  29  22.621  29  23.241  29  37.878  29  48.822  29  61.595  29  75.938  29  90.908  29  106.8   29  122.27
30  21.814  30  22.052  30  26.041  30  36.598  30  52.416  30  71.902  30  94.63   30  119.08  30  145.17  30  171.71
31  21.814  31  22.982  31  26.144  31  35.349  31  55.267  31  74.648  31  97.026  31  122.61  31  151.05  31  179.36
32  23.789  32  25.4    32  37.409  32  36.506  32  63.395  32  130.2   32  164.9   32  193.87  32  222.34  32  250.93
33  23.112  33  25.69   33  37.432  33  48.23   33  55.945  33  60.769  33  64.731  33  66.258  33  70.594  33  73.944
34  21.969  34  24.529  34  32.375  34  46.886  34  60.913  34  77.552  34  95.939  34  114.89  34  134.47  34  193.7
35  21.988  35  23.243  35  24.996  35  26.704  35  26.649  35  32.682  35  36.27   35  39.562  35  44.405  35  45.605
36  21.91   36  23.95   36  26.041  36  28.863  36  31.35   36  33.142  36  36.557  36  40.498  36  44.633  36  48.379
37  21.968  37  23.679  37  26.138  37  28.343  37  26.668  37  32.701  37  35.626  37  39.659  37  43.968  37  46.7
38  22.046  38  22.905  38  24.341  38  26.222  38  28.965  38  32.279  38  35.926  38  39.907  38  44.462  38  45.154
39  21.678  39  21.684  39  21.707  39  21.772  39  21.694  39  22.153  39  22.663  39  23.268  39  24.241  39  25.454
40  2.435   40  2.4356  40  2.436   40  2.4367  40  2.4372  40  2.4379  40  2.4384  40  2.4391  40  2.4336  40  2.4402
41  21.251  41  21.257  41  21.281  41  21.387  41  21.409  41  21.629  41  22.803  41  22.649  41  23.545  41  24.789
42  21.678  42  21.684  42  21.668  42  21.734  42  21.913  42  22.25   42  22.836  42  23.675  42  24.576  42  25.604
43  21.232  43  21.218  43  21.242  43  21.387  43  21.467  43  21.823  43  22.429  43  23.346  43  24.647  43  26.334
44  .2573   44  .62382  44  1.3363  44  2.9046  44  4.7564  44  7.0681  44  9.9683  44  13.694  44  18.351  44  24.165
45  6.285   45  42.113  45  78.225  45  114.47  45  150.73  45  186.98  45  223.9   45  260.76  45  298.5   45  325.95


SCAN # 11   SCAN # 12   SCAN # 13   SCAN # 14   SCAN # 15   SCAN # 16   SCAN # 17   SCAN # 18   SCAN # 19   SCAN # 20

 1 51.359    1 57.952    1 55.149    1 57.034    1 57.345    1 58.724    1 60.596    1 66.33     1 62.123    1 61.449
 2 48.266    2 54.139    2 55.28     2 56.797    2 58.645    2 58.301    2 59.382    2 60.07     2 61.604    2 61.56
 3 -126270   3 -117260   3 -171190   3 -307040   3 -74279    3 -417560   3 22020     3 -168660   3 22993     3 -211650
 4 52.699    4 58.502    4 59.791    4 57.609    4 59.861    4 58.646    4 61.305    4 60.528    4 62.944    4 61.446
 5 52.211    5 57.923    5 55.241    5 56.941    5 59.861    5 58.255    5 60.711    5 59.932    5 62.152    5 60.943
 6 52.165    6 57.396    6 59.241    6 56.688    6 58.852    6 58.324    6 60.274    6 59.749    6 61.981    6 60.92
 7 51.466    7 55.932    7 56.745    7 57.011    7 56.763    7 58.577    7 60.317    7 60.824    7 62.79     7 61.16
 8 52.164    8 57.537    8 59.722    8 57.149    8 59.858    8 58.83     8 60.905    8 60.07     8 62.426    8 61.583
 9 55.344    9 59.1      9 57.862    9 58        9 56.666    9 59.724    9 59.955    9 62.173    9 61.264    9 60.679
10  64.752  10  71.889  10  70.545  10  62.397  10  58.847  10  61.737  10  59.589  10  63.13   10  60.85   10  60.853
11  57.349  11  64.974  11  62.181  11  61.233  11  57.909  11  61.76   11  59.428  11  63.153  11  60.761  11  60.808
12  68.828  12  77.286  12  73.525  12  65.649  12  66.012  12  61.92   12  64.018  12  63.29   12  65.541  12  62.194
13  47.984  13  53.377  13  54.493  13  56.157  13  57.564  13  57.772  13  58.806  13  59.52   13  61.147  13  60.929
14  51.732  14  56.639  14  57.356  14  56.019  14  57.127  14  58.278  14  59.634  14  59.703  14  60.896  14  60.675
15  61.366  15  66.495  15  63.591  15  61.462  15  57.794  15  62.011  15  59.29   15  63.358  15  60.713  15  60.852
16  51.978  16  58.113  16  53.447  16  56.619  16  53.185  16  58.692  16  60.093  16  60.711  16  61.536  16  61.446
17  41.453  17  53.557  17  56.880  17  56.526  17  57.081  17  57.641  17  58.464  17  59.657  17  60.967  17  [illegible]
18  52.908  18  58.641  18  56.73   18  57.747  18  57.909  18  58.99   18  59.497  18  60.871  18  60.731  18  60.652
19  2232    19  2252.3  19  2298.4  19  2332.4  19  2371.4  19  2556.5  19  2437.5  19  2619.5  19  2498.6  19  2503
20  2.486   20  2.4865  20  2.4868  20  2.4868  20  2.4869  20  2.487   20  2.4872  20  2.4873  20  2.4874  20  2.4876
21  47.538  21  50.952  21  56.516  21  56.711  21  58.847  21  58.301  21  59.585  21  59.955  21  [illegible]  21  61.583
22  44.763  22  52.286  22  53.543  22  57.08   22  58.139  22  58.761  22  59.064  22  60.462  22  61.399  22  62.017
23  47.307  23  52.853  23  53.914  23  57.103  23  58.139  23  58.83   23  59.932  23  60.482  23  61.399  23  62.017
24  49.319  24  54.768  24  58.437  24  57.402  24  58.3    24  58.875  24  60.299  24  60.551  24  61.855  24  61.984
25  49.412  25  54.768  25  57.241  25  57.011  25  56.76   25  58.944  25  60.23   25  60.642  25  61.764  25  61.994
26  119.23  26  131.76  26  139.81  26  122.18  26  117.83  26  119.33  26  117.79  26  121.19  26  122.42  26  123.44
27  93.123  27  93.272  27  57.35   27  63.873  27  56.42   27  67.850  27  59.813  27  65.014  27  61.34   27  61.376
28  113.43  28  138.19  28  64.595  28  95.271  28  60.921  28  95.328  28  62.326  28  95.202  28  63.373  28  64.134
29  138.05  29  123.44  29  151.59  29  146.28  29  142.82  29  150.82  29  141.95  29  145.47  29  147.54  29  [illegible]
30  195.44  30  228.21  30  233.57  30  240.24  30  245.46  30  252.07  30  257.26  30  263.63  30  269     30  273.04
31  247.4   31  235.05  31  240.13  31  246.25  31  249.3   31  255.26  31  260.02  31  265.81  31  270.48  31  274.61
32  230.98  32  309.48  32  314.49  32  321.13  32  326.25  32  332.84  32  338.11  32  344.45  32  349.38  32  353.13
33  78.646  33  85.271  33  88.363  33  92.374  33  94.829  33  104.79  33  108.25  33  110.24  33  108.15  33  [illegible]
34  173.05  34  131.39  34  131.12  34  170.26  34  129.81  34  161.84  34  138.48  34  164.45  34  136.75  34  119.62
35  52.925  35  55.464  35  56.882  35  60.375  35  58.952  35  61.635  35  60.132  35  63.796  35  61.719  35  61.683
36  53.362  36  58.432  36  56.139  36  61.633  36  58.891  36  62.198  36  60.365  36  64.19   36  62.147  36  62.377
37  52.333  37  57.663  37  55.724  37  60.634  37  58.59   37  61.936  37  60.676  37  63.756  37  61.734  37  61.683
38  54.877  38  59.582  38  56.214  38  60.488  38  58.458  38  61.579  38  60.82   38  63.308  38  61.621  38  61.733
39  27.171  39  [illegible]  39  29.74   39  34.3    39  30.762  39  31.376  39  31.897  39  34.233  39  33.022  39  33.973
40  2.4409  40  2.4415  40  2.4416  40  2.4418  40  2.4419  40  2.442   40  2.442   40  2.4423  40  2.4425  40  2.4424
41  26.333  41  30.449  41  28.654  41  29.355  41  29.856  41  30.917  41  30.917  41  31.535  41  32.056  41  [illegible]
42  28.77   42  31.469  42  31.893  42  32.739  42  33.22   42  34.183  42  34.64   42  35.581  42  36.158  42  36.731
43  28.559  43  31.277  43  31.625  43  32.567  43  33.163  43  33.941  43  34.583  43  35.35   43  36.081  43  36.616
44  31.405  44  40.449  44  28.584  44  37.424  44  38.623  44  38.043  44  32.322  44  39.886  44  34.503  44  34.58
45  373.11  45  414.73  45  422.36  45  431.6   45  439.12  45  448.33  45  455.86  45  465.88  45  472.61  45  478.43
```

```
SCAN # 21   SCAN # 22   SCAN # 23   SCAN # 24   SCAN # 25   SCAN # 26

 1  61.606   1  61.653   1  61.655   1  61.677   1  61.677   1  61.679
 2  61.452   2  61.79    2  61.723   2  61.86    2  61.883   2  61.93
 3 -123460   3 -43742    3  11579    3 -21319    3 -35755    3 -48918
 4  61.56    4  61.653   4  61.7     4  61.769   4  61.814   4  61.862
 5  61.335   5  61.081   5  61.152   5  61.198   5  61.243   5  61.291
 6  60.989   6  61.081   6  61.106   6  61.22    6  61.243   6  61.291
 7  61.606   7  61.721   7  61.7     7  61.837   7  61.837   7  61.93
 8  61.629   8  61.744   8  61.746   8  61.883   8  61.883   8  61.976
 9  60.943   9  61.013   9  61.06    9  61.106   9  61.129   9  61.199
10  60.966  10  61.036  10  61.106  10  61.175  10  61.152  10  61.222
11  60.658  11  60.967  11  61.015  11  61.06   11  61.106  11  61.154
12  64.03   12  65.226  12  65.387  12  65.183  12  64.592  12  64.231
13  61.058  13  61.127  13  61.152  13  61.196  13  61.243  13  61.337
14  61.012  14  61.081  14  61.129  14  61.198  14  61.266  14  61.291
15  60.92   15  60.99   15  61.06   15  61.083  15  61.175  15  61.199
16  61.538  16  61.63   16  61.677  16  61.746  16  61.769  16  61.862
17  60.989  17  61.104  17  61.175  17  61.22   17  61.243  17  61.337
18  60.966  18  61.036  18  61.083  18  61.152  18  61.198  18  61.245
19  2506.7  19  2509.7  19  2510.8  19  2513.0  19  2515.9  19  2517.9
20  2.4876  20  2.4877  20  2.4879  20  2.4879  20  2.4879  20  2.4881
21  61.629  21  61.675  21  61.677  21  61.723  21  61.814  21  61.839
22  62.154  22  62.223  22  62.202  22  62.271  22  62.362  22  62.341
23  62.108  23  62.2    23  62.18   23  62.294  23  62.362  23  62.364
24  62.063  24  62.2    24  62.18   24  62.316  24  62.362  24  62.387
25  62.017  25  62.155  25  62.225  25  62.202  25  62.271  25  62.341
26  125.01  26  124.77  26  125.81  26  125.05  26  126.31  26  125.29
27  61.453  27  61.529  27  61.604  27  61.662  27  61.701  27  61.777
28  64.949  28  64.175  28  66.16   28  66.816  28  65.939  28  71.025
29  147.66  29  150.41  29  154.01  29  156.24  29  [illegible]  29  159.1
30  277.44  30  291.74  30  296.01  30  290.31  30  294.55  30  298.76
31  277.91  31  281.59  31  285.29  31  288.96  31  292.6   31  296.22
32  357.17  32  361.15  32  365.08  32  369.07  32  373.01  32  376.34
33  108.55  33  111.76  33  119.77  33  120.4   33  122.66  33  115.94
34  127.16  34  135.36  34  141.03  34  138.27  34  139.80  34  143.5
35  61.979  35  62.036  35  62.074  35  62.094  35  62.171  35  62.228
36  62.373  36  62.412  36  62.412  36  62.469  36  62.471  36  62.566
37  62.017  37  62.074  37  62.093  37  62.187  37  62.246  37  62.303
38  61.829  38  61.867  38  61.924  38  61.981  38  62.058  38  62.096
39  34.914  39  34.494  39  34.992  39  35.431  39  35.99   39  36.527
40  2.4426  40  2.4427  40  2.4427  40  2.4428  40  2.443   40  2.4431
41  32.92   41  33.362  41  33.842  41  34.341  41  34.842  41  35.321
42  37.287  42  37.919  42  38.53   42  39.142  42  39.793  42  40.433
43  37.211  43  37.795  43  38.377  43  38.97   43  39.602  43  40.222
44  34.619  44  34.636  44  34.7    44  34.747  44  34.79   44  34.855
45  484.76  45  490.30  45  497.22  45  503.45  45  509.68  45  515.92
```

RUN NUMBER 2

Q_{IN} = 65 KW/m^2, Set pressure of the PRV = 35 psig.
Liquid level = 58% (81.2 deg. with the vertical)
PRV orifice diameter = 1/4 in.
No internal protection.

```
SCAN # 1     SCAN # 2     SCAN # 3     SCAN # 4     SCAN # 5     SCAN # 6     SCAN # 7     SCAN # 8     SCAN # 9     SCAN # 10

 1  20.423    1  20.645    1  21.251    1  22.55     1  25.249    1  26.129    1  32.154    1  36.313    1  40.539    1  45.473
 2  20.493    2  20.472    2  20.979    2  21.957    2  23.378    2  27.102    2  30.26     2  34.147    2  39.056    2  42.256
 3  80533     3  26425     3 -12215     3 -22621     3 -47584     3 -53009     3 -72295     3 -35851     3 [illegible] 3 -33759
 4  20.558    4  20.67     4  21.103    4  22.806    4  24.216    4  26.955    4  30.528    4  34.75     4  38.537    4  43.85
 5  20.533    5  20.67     5  21.128    5  22.031    5  24.413    5  27.273    5  31.014    5  35.304    5  39.478    5  44.16
 6  20.533    6  20.67     6  21.177    6  22.179    6  25.102    6  28.202    6  31.014    6  36.081    6  40.606    6  44.906
 7  20.533    7  20.521    7  21.227    7  22.155    7  23.649    7  27.322    7  31.133    7  34.581    7  39.271    7  43.749
 8  20.533    8  20.546    8  21.474    8  22.624    8  24.216    8  27.518    8  31.281    8  35.063    8  39.367    8  44.08
 9  20.558    9  20.67     9  21.078    9  22.006    9  23.994    9  26.802    9  32.372    9  36.682    9  40.154    9  48.293
10  20.558   10  20.645   10  21.152   10  22.105   10  24.265   10  27.175   10  30.62    10  40.046   10  47.228   10  54.744
11  20.533   11  20.645   11  21.078   11  22.031   11  24.191   11  27.102   11  30.147   11  [illegible] 11  45.113  11  51.704
12  20.533   12  20.645   12  21.326   12  23.414   12  25.501   12  30.639   12  35.846   12  41.83    12  44.618   12  50.939
13  20.434   13  20.472   13  20.855   13  21.66    13  23.378   13  27.904   13  30.332   13  34.133   13  38.695   13  42.303
14  20.508   14  20.745   14  21.0     14  22.737   14  25.249   14  30.691   14  32.323   14  36.674   14  40.527   14  45.033
15  20.533   15  20.645   15  21.103   15  22.06    15  24.29    15  27.175   15  30.668   15  34.918   15  44.519   15  [illegible]
16  20.508   16  20.645   16  21.152   16  22.204   16  25.004   16  28.08    16  32.081   16  36.402   16  40.702   16  45.446
17  20.458   17  20.472   17  20.881   17  21.462   17  23.994   17  26.657   17  29.822   17  33.737   17  37.118   17  [illegible]
18  20.533   18  20.645   18  21.078   18  21.982   18  23.945   18  26.833   18  30.406   18  34.436   18  38.626   18  45.166
19  849.9    19  315.42   19  631.87   19  872.36   19  962.89   19  1126.4   19  1332.9   19  1397.3   19  1778.8   19  2021.[illegible]
20  2.4561   20  2.4574   20  2.4585   20  2.4597   20  2.461    20  2.4623   20  2.4634   20  2.4645   20  2.4650   20  2.4660
21  20.583   21  20.596   21  21.375   21  21.987   21  23.649   21  27.249   21  30.59    21  34.685   21  38.602   21  42.895
22  20.657   22  20.645   22  21.078   22  21.704   22  23.674   22  27.567   22  31.038   22  34.726   22  38.665   22  42.683
23  20.682   23  20.655   23  21.202   23  21.462   23  23.501   23  27.249   23  31.135   23  34.677   23  39.224   23  [illegible]
24  20.707   24  20.635   24  21.103   24  22.13    24  23.97    24  27.616   24  31.533   24  34.991   24  39.08    24  43.139
25  20.682   25  20.67    25  20.929   25  21.734   25  23.477   25  27.2     25  30.732   25  34.581   25  [illegible] 25  [illegible]
26  20.577   26  21.164   26  23.645   26  28.515   26  36.122   26  45.637   26  56.591   26  69.201   26  82.683   26  97.682
27  20.597   27  21.332   27  24.645   27  30.036   27  37.9     27  47.667   27  58.734   27  71.61    27  85.612   27  101.14
28  20.577   28  21.551   28  24.843   28  30.42    28  38.778   28  49.164   28  60.974   28  74.072   28  88.277   28  104.85
29  20.597   29  21.571   29  25.154   29  31.17    29  44.572   29  52.172   29  65.438   29  79.821   29  95.257   29  111.4
30  20.577   30  20.678   30  22.542   30  29.17    30  42.382   30  60.012   30  80.876   30  104.23   30  139.95   30  159.32
31  20.655   31  21.551   31  24.69    31  32.419   31  46.283   31  63.879   31  84.29    31  108.14   31  174.37   31  162.54
32  21.136   32  21.823   32  29.916   32  45.401   32  78.48    32  106.61   32  146.82   32  175.85   32  203.[illegible] 32  233.53
33  20.731   33  24.017   33  27.732   33  35.562   33  44.284   33  51.567   33  61.087   33  58.42    33  59.[illegible] 33  61.624
34  20.577   34  23.605   34  26.525   34  36.366   34  50.239   34  65.584   34  83.01    34  132.18   34  132.30   34  144.[illegible]
35  20.539   35  21.803   35  23.249   35  25.66    35  29.572   35  29.671   35  33.275   35  37.376   35  41.84    35  [illegible]
36  20.442   36  22.191   36  24.439   36  27.224   36  29.655   36  30.159   36  34.444   36  38.369   36  42.625   36  [illegible]
37  20.44    37  22.54    37  24.633   37  26.297   37  29.693   37  29.62    37  33.121   37  37.299   37  41.44    37  45.624
38  20.616   38  21.61    38  24.69    38  29.266   38  28.172   38  31.044   38  34.981   38  38.554   38  42.758   38  [illegible]
39  20.674   39  20.639   39  20.68    39  20.704   39  20.805   39  20.984   39  21.236   39  21.645   39  21.845   39  23.633
40  2.4394   40  2.4398   40  2.44     40  2.4404   40  2.4408   40  2.4612   40  2.4416   40  2.4419   40  2.4423   40  2.4428
41  20.5     41  20.444   41  20.525   41  20.529   41  20.572   41  20.731   41  21.087   41  21.476   41  [illegible] 41  23.628
42  20.315   42  20.329   42  20.331   42  20.374   42  20.475   42  20.693   42  21.104   42  21.766   42  [illegible] 42  24.061
43  20.364   43  20.368   43  20.37    43  20.393   43  20.514   43  20.751   43  21.22    43  21.56    43  23.03    43  [illegible]
44 -.00429   44  .13749   44  .34374   44  .91949   44  2.2042   44  3.9616   44  6.4408   44  9.4699   44  12.98    44  17.[illegible]
45  8.327    45  35.731   45  64.816   45  96.384   45  132.49   45  168.75   45  204.37   45  241.47   45  277.96   45  318.82
```

```
SCAN # 11   SCAN # 12   SCAN # 13   SCAN # 14   SCAN # 15   SCAN # 16   SCAN # 17   SCAN # 18   SCAN # 19   SCAN # 20

 1   50.663   1   56.406   1   62.562   1   61.217   1   62.291   1   61.996   1   61.816   1   60.857   1   60.697   1   60.538
 2   48.514   2   53.36    2   59.75    2   60.714   2   60.349   2   62.384   2   61.633   2   61.519   2   61.383   2   61.214
 3  -39251    3  -65465    3   2338.6   3  -54424    3  -56469    3  -47249    3  -99818    3  -30484    3  -7812     3  -13965
 4   49.474   4   58.248   4   66.446   4   67.94    4   64.749   4   62.224   4   62.283   4   62.045   4   62.182   4   62.275
 5   49.451   5   55.596   5   61.832   5   68.884   5   62.382   5   61.471   5   60.981   5   60.788   5   60.653   5   60.515
 6   50.325   6   56.813   6   62.493   6   62.586   6   62.428   6   61.448   6   60.879   6   60.742   6   60.629   6   60.492
 7   48.953   7   54.094   7   59.681   7   60.782   7   60.669   7   62.66    7   61.364   7   61.942   7   61.36    7   61.224
 8   49.193   8   54.649   8   60.323   8   61.263   8   60.715   8   62.544   8   61.678   8   61.563   8   61.406   8   61.27
 9   55.68    9   65.006   9   73.575   9   74.626   9   68.55    9   61.425   9   60.879   9   60.765   9   60.629   9   60.469
10    64.612 10    75.149 10    87.328 10    86.457 10    75.806 10    74.16  10    67.741 10    65.23  10    64.527 10    63.669
11    60.165 11    70.697 11    80.481 11    80.593 11    72.382 11    69.633 11    64.366 11    63.287 11    63.073 11    63.004
12    70.081 12    81.398 12    95.801 12    91.982 12    77.674 12    77.498 12    69.68  12    66.793 12    66.636 12    64.574
13    47.459 13    52.816 13    59.2   13    59.839 13    59.913 13    61.517 13    61.061 13    60.948 13    60.729 13    60.653
14    51.039 14    55.343 14    61.512 14    60.884 14    61.538 14    61.105 14    61.839 14    60.902 14    60.743 14    60.63
15    62.359 15    73.095 15    34.679 15    83.521 15    74.448 15    66.664 15    61.29  15    61.817 15    60.88  15    60.744
16    50.759 16    56.59  16    63.177 16    59.981 16    63.316 16    61.654 16    61.404 16    61.337 16    61.201 16    61.064
17    46.943 17    54.655 17    58.097 17    59.758 17    60.828 17    61.151 17    61.639 17    60.925 17    60.812 17    60.653
18    54.778 18    62.027 18    70.259 18    71.338 18    67.105 18    62.817 18    61.496 18    61.177 18    61.018 18    61.064
19    2367.7 19    2797.1 19    3145.6 19    3132.7 19    2886.7 19    2509.8 19    2504.9 19    2500.9 19    2494   19    2400
20    2.4679 20    2.469  20    2.4701 20    2.4703 20    2.4704 20    2.4706 20    2.4708 20    2.4709 20    2.471  20    2.4711
21    47.67  21    52.641 21    57.867 21    59.798 21    60.669 21    61.517 21    61.336 21    61.245 21    61.063 21    60.75
22    47.858 22    53.607 22    59.429 22    60.141 22    60.921 22    62.11  22    61.907 22    61.771 22    61.635 22    61.476
23    47.611 23    54.163 23    60.004 23    60.164 23    60.988 23    62.067 23    61.907 23    61.748 23    61.635 23    61.476
24    48.782 24    54.001 24    59.406 24    60.279 24    61.035 24    62.042 24    61.907 24    61.771 24    61.635 24    61.476
25    47.318 25    54.302 25    58.465 25    60.348 25    60.675 25    61.973 25    61.884 25    61.748 25    61.612 25    61.476
26    112.88 26    128.52 26    144.63 26    142.53 26    135.23 26    134.59 26    128.4  26    129.99 26    124.01 26    122.75
27    [illegible] 27 135.11 27    152.74 27    152.14 27    140.96 27    144.9  27    146.18 27    145.6  27    [illegible] 27 [illegible]
28    121.51 28    138.65 28    155.51 28    153.81 28    147.83 28    147.59 28    143.76 28    142.78 28    143.69 28    143.33
29    128.94 29    146.95 29    164.84 29    162.84 29    150.08 29    157.37 29    153.68 29    150.66 29    150.08 29    153.91
30    182.61 30    211.88 30    239.68 30    244.96 30    251.36 30    256.6  30    260.64 30    264.6  30    268.33 30    272.44
31    190.4  31    217.83 31    244.13 31    248.87 31    254.69 31    259.41 31    263.82 31    266.53 31    270.07 31    273.55
32    264.25 32    295.88 32    322.11 32    326.67 32    332.55 32    337.39 32    341.16 32    344.81 32    348.44 32    352.83
33    64.965 33    66.674 33    74.855 33    75.212 33    76.386 33    77.284 33    74.301 33    78.897 33    81.146 33    82.463
34    166.99 34    190.44 34    213.84 34    217.83 34    217.83 34    221.88 34    223.81 34    224.62 34    226.78 34    225.01
35    50.868 35    56.741 35    63.268 35    60.68  35    63.478 35    62.071 35    61.903 35    61.732 35    61.663 35    61.378
36    51.625 36    57.25  36    62.967 36    61.131 36    63.965 36    62.446 36    62.334 36    62.164 36    [illegible] 36 61.423
37    50.679 37    55.911 37    63.174 37    60.661 37    64.003 37    62.685 37    61.94  37    [illegible] 37 61.603 37    61.435
38    52.74  38    56.323 38    64.205 38    60.492 38    64.153 38    61.92  38    61.752 38    61.603 38    61.434 38    61.247
39    [illegible] 39 26.848 39    29.224 39    29.727 39    [illegible] 39 30.944 39    31.229 39    31.633 39    [illegible] 39 [illegible]
40    2.4432 40    2.4435 40    2.4439 40    2.4442 40    2.4443 40    2.4443 40    2.4444 40    2.4444 40    2.4445 40    2.4446
41    24.587 41    26.408 41    28.846 41    29.111 41    29.769 41    30.289 41    30.614 41    30.955 41    31.403 41    31.608
42    25.843 42    28.161 42    30.974 42    31.573 42    32.227 42    32.66  42    33.322 42    33.763 42    [illegible] 42 34.723
43    26.46  43    28.931 43    31.373 43    32.591 43    33.34  43    34.011 43    34.511 43    35.009 43    35.466 43    36.035
44    23.865 44    30.171 44    38.907 44    32.234 44    38.223 44    34.004 44    33.763 44    33.331 44    33.265 44    33.824
45    354.24 45    354.26 45    434.8  45    442.34 45    451.47 45    459.01 45    464.84 45    470.58 45    476.32 45    482.05
```

```
SCAN # 21   SCAN # 22   SCAN # 23   SCAN # 24   SCAN # 25   SCAN # 26   SCAN # 27   SCAN # 28   SCAN # 29   SCAN # 30

 1   62.687   1   62.37    1   61.777   1   61.573   1   61.391   1   61.289   1   61.028   1   60.869   1   [illegible] 1 63.063
 2   61.409   2   62.506   2   62.462   2   62.29    2   62.099   2   61.917   2   61.736   2   [illegible] 2 [illegible] 2 [illegible]
 3  -45325    3  -9350.8   3   45279    3  -11690    3   11045    3   28650    3   25873    3   35673    3   43334    3   67291
 4   63.393   4   63.668   4   63.601   4   63.67    4   63.603   4   63.49    4   63.378   4   63.219   4   63.13    4   63.814
 5   62.224   5   62.21    5   61.754   5   61.618   5   61.414   5   61.255   5   61.074   5   [illegible] 5 [illegible] 5 63.222
 6   64.665   6   62.303   6   62.051   6   61.892   6   61.391   6   61.506   6   61.348   6   60.292   6   [illegible] 6 [illegible]
 7   61.455   7   62.603   7   62.462   7   62.257   7   62.076   7   61.963   7   61.736   7   61.6     7   61.373   7   [illegible]
 8   61.937   8   62.826   8   62.53    8   62.349   8   62.19    8   61.985   8   61.805   8   61.623   8   61.46    8   [illegible]
 9   [illegible] 9 62.048   9   63.396   9   63.533   9   63.557   9   63.603   9   63.563   9   63.424   9   63.335   9   64.221
10    63.314 10    71.976 10    67.771 10    65.668 10    64.853 10    64.684 10    64.287 10    64.038 10    [illegible] 10 66.659
11    64.737 11    67.341 11    66.833 11    65.147 11    64.671 11    64.467 11    64.242 11    [illegible] 11 63.231 11    65.948
12    68.806 12    75.795 12    68.335 12    65.668 12    64.398 12    64.195 12    63.501 12    63.606 12    63.354 12    [illegible]
13    59.863 13    62.21  13    61.914 13    61.755 13    61.551 13    61.369 13    61.211 13    61.052 13    60.593 13    61.329
14    63.037 14    61.89  14    61.823 14    61.595 14    61.391 14    61.186 14    61.628 14    60.869 14    [illegible] 14 63.472
15    63.53  15    62.392 15    62.142 15    62.029 15    62.03  15    62.875 15    63.446 15    63.674 15    63.699 15    66.808
16    63.757 16    62.552 16    62.348 16    62.964 16    63.238 16    63.034 16    63.036 16    63.219 16    63.239 16    64.246
17    63.863 17    62.073 17    61.691 17    61.71  17    61.528 17    61.346 17    61.138 17    61.006 17    [illegible] 17 61.306
18    63.282 18    63.144 18    62.282 18    63.397 18    63.375 18    63.376 18    63.309 18    63.128 18    61.062 18    64.132
19    2612.1 19    2555.2 19    2543.2 19    2536.2 19    2585.3 19    2614.3 19    2628.4 19    2618.4 19    2617.5 19    2694.6
20    2.4713 20    2.4715 20    2.4716 20    2.4717 20    2.4718 20    2.4719 20    2.4721 20    2.4722 20    2.4724 20    2.4725
21    61.34  21    62.415 21    62.188 21    62.006 21    61.825 21    61.643 21    61.439 21    [illegible] 21 61.122 21    61.796
22    61.797 22    62.962 22    62.735 22    62.554 22    62.35  22    62.191 22    62.01  22    61.806 22    [illegible] 22 62.082
23    61.889 23    62.939 23    62.735 23    62.554 23    62.372 23    62.191 23    62.01  23    61.828 23    [illegible] 23 62.037
24    61.98  24    62.917 24    62.735 24    62.577 24    62.372 24    62.191 24    62.01  24    61.828 24    [illegible] 24 62.333
25    61.98  25    62.917 25    62.713 25    62.531 25    62.35  25    62.168 25    61.967 25    61.828 25    61.67  25    62.288
26    120.55 26    132.41 26    130.66 26    129.44 26    129.24 26    129.32 26    129.99 26    130.37 26    [illegible] 26 [illegible]
27    153.99 27    156.6  27    156.49 27    158    27    159.55 27    161.25 27    164.33 27    [illegible] 27 164.02 27    [illegible]
28    149.23 28    151.48 28    151.82 28    152.42 28    153.11 28    154.88 28    157.73 28    158.9  28    [illegible] 28 166.39
29    158.83 29    160.93 29    159.17 29    159.48 29    160.86 29    162.9  29    164.62 29    166.39 29    [illegible] 29 [illegible]
30    278.72 30    283.87 30    287.77 30    291.66 30    295.55 30    299.38 30    303.24 30    307.06 30    [illegible] 30 [illegible]
31    278.92 31    283.34 31    286.81 31    290.13 31    293.49 31    296.78 31    300.01 31    [illegible] 31 306.46 31    [illegible]
32    357.72 32    362.38 32    365.95 32    369.4  32    372.88 32    376.33 32    379.7  32    383.31 32    386.48 32    392.09
33    82.261 33    61.964 33    83.506 33    83.153 33    84.335 33    85.1   33    86.453 33    88.765 33    90.431 33    91.3
34    234    34    239.33 34    241.08 34    243.11 34    245.98 34    249.15 34    252.37 34    255.37 34    [illegible] 34 263.93
35    63.763 35    62.9   35    62.733 35    62.641 35    62.189 35    62.082 35    61.872 35    61.703 35    [illegible] 35 64.856
36    64.475 36    63.257 36    63.89  36    62.94  36    62.752 36    62.622 36    62.397 36    62.21  36    62.804 36    64.5
37    63.6   37    62.881 37    62.696 37    62.508 37    62.32  37    62.115 37    61.966 37    61.778 37    61.61  37    64.067
38    64.531 38    62.675 38    62.508 38    62.32  38    62.151 38    61.946 38    61.778 38    61.609 38    61.441 38    [illegible]
39    33.191 39    33.804 39    34.266 39    34.745 39    [illegible] 39 35.665 39    36.163 39    36.7   39    [illegible] 39 38.059
40    2.4447 40    2.4447 40    2.4449 40    2.4449 40    2.4449 40    2.445  40    2.4451 40    2.4451 40    2.4452 40    2.4453
41    32.5   41    33.075 41    33.557 41    33.998 41    34.439 41    34.938 41    35.399 41    35.856 41    36.395 41    37.218
42    35.567 42    36.352 42    36.87  42    37.386 42    37.883 42    38.419 42    38.974 42    39.546 42    40.139 42    41.307
43    36.868 43    37.652 43    38.227 43    38.8   43    39.353 43    39.927 43    40.538 43    41.129 43    41.74  43    42.788
44    38.12  44    34.982 44    34.653 44    34.378 44    34.12  44    33.875 44    33.613 44    33.385 44    33.158 44    36.64
45    491.17 45    498.71 45    504.46 45    510.19 45    515.92 45    521.66 45    527.39 45    533.13 45    538.86 45    548.18
```

RUN NUMBER 3

Q_{IN} = 65 KW/m^2, Set pressure of the PRV = 35 psig.

Liquid level = 23% (124.6 deg. with the vertical)

PRV orifice diameter = 1/4 in.

No internal protection.

```
SCAN # 1
 1  20.694
 2  20.943
 3 -12526
 4  21.171
 5  21.216
 6  21.042
 7  21.117
 8  21.117
 9  21.34
10  21.334
11  21.446
12  22.33
13  20.795
14  20.619
15  21.667
16  20.323
17  20.694
18  21.117
19  632.44
20  2.3319
21  18.253
22  18.763
23  [illegible]
24  15.155
25  19.404
26  21.426
27  21.44
28  21.555
29  22.032
30  21.421
31  [illegible]
32  21.343
33  21.395
34  21.479
35  20.955
36  19.965
37  19.546
38  21.11
39  22.022
40  2.4751
41  21.731
42  21.44
43  21.734
44  3.3653
45  6.326
```

```
SCAN # 2
 1  21.608
 2  21.682
 3 -17163
 4  21.781
 5  21.83
 6  21.657
 7  21.67
 8  21.66
 9  21.806
10  22.449
11  22.177
12  22.644
13  21.286
14  22.323
15  22.3
16  21.434
17  22.053
18  21.608
19  852.25
20  2.3313
21  18.403
22  16.529
23  15.596
24  17.546
25  20.864
26  22.766
27  22.523
28  23.001
29  23.775
30  21.547
31  22.129
32  23.059
33  22.362
34  24.239
35  23.814
36  19.975
37  21.392
38  22.497
39  22.032
40  2.4742
41  21.722
42  21.412
43  21.315
44  4.4901
45  37.762
```

```
SCAN # 3
 1  22.102
 2  22.308
 3 -18642
 4  22.258
 5  22.332
 6  22.104
 7  22.362
 8  22.555
 9  22.06
10  22.728
11  22.289
12  23.049
13  21.768
14  23.063
15  22.357
16  22.53
17  23.197
18  21.862
19  861.55
20  2.3419
21  18.664
22  19.58
23  20.740
24  20.698
25  22.407
26  26.259
27  27.706
28  27.629
29  25.767
30  24.559
31  26.549
32  37.973
33  24.570
34  33.11
35  31.247
36  19.966
37  23.082
38  27.012
39  22.062
40  2.4733
41  21.732
42  21.403
43  21.386
44  5.6345
45  72.744
```

```
SCAN # 4
 1  22.782
 2  22.88
 3  29196
 4  22.732
 5  22.806
 6  22.683
 7  22.93
 8  23.177
 9  22.559
10  24.235
11  22.954
12  24.729
13  22.267
14  25.294
15  23.769
16  23.621
17  24.335
18  22.287
19  880.72
20  2.3522
21  19.734
22  21.322
23  21.57
24  21.421
25  23.966
26  31.723
27  34.716
28  34.677
29  38.083
30  23.757
31  34.611
32  63.904
33  29.088
34  44.865
35  41.536
36  28.039
37  25.946
38  34.864
39  22.857
40  2.4709
41  21.708
42  21.437
43  21.32
44  6.8361
45  108.27
```

```
SCAN # 5
 1  23.422
 2  23.37
 3 -1275.3
 4  23.274
 5  23.397
 6  23.290
 7  23.594
 8  23.866
 9  23.126
10  27.377
11  25.71
12  28.306
13  22.953
14  26.912
15  26.691
16  24.826
17  23.759
18  22.829
19  942.66
20  2.3619
21  21.469
22  23.619
23  22.656
24  22.31
25  27.744
26  39.333
27  43.277
28  42.877
29  48.252
30  48.490
31  51.76
32  94.34
33  35.376
34  59.351
35  55.868
36  28.456
37  26.502
38  43.657
39  22.163
40  2.4718
41  21.795
42  21.581
43  21.465
44  8.0621
45  144.21
```

```
SCAN # 6
 1  24.4
 2  24.744
 3 -29445
 4  24.170
 5  24.351
 6  24.283
 7  24.646
 8  24.916
 9  24.449
10  30.345
11  26.034
12  31.972
13  24.254
14  29.055
15  29.396
16  26.341
17  29.25
18  23.735
19  1034.3
20  2.371
21  23.907
22  27.174
23  25.113
24  24.744
25  35.665
26  47.941
27  53.277
28  51.765
29  61.035
30  67.463
31  69.241
32  120.03
33  41.423
34  76.402
35  72.452
36  21.09
37  31.552
38  55.804
39  22.311
40  2.4711
41  21.923
42  21.665
43  21.749
44  9.5773
45  180.7
```

```
SCAN # 7
 1  25.788
 2  27.65
 3 -3572.2
 4  25.42
 5  25.666
 6  25.469
 7  26.23
 8  26.451
 9  27.253
10  36.990
11  31.607
12  28.315
13  27.357
14  31.984
15  35.629
16  28.286
17  35.172
18  25.248
19  1160.8
20  2.3796
21  27.67
22  31.232
23  29.237
24  38.357
25  49.033
26  57.852
27  64.6
28  62.494
29  75.465
30  89.286
31  69.564
32  142.78
33  46.674
34  95.213
35  69.305
36  22.220
37  34.041
38  70.206
39  23.615
40  2.4705
41  22.228
42  22.46
43  22.305
44  11.425
45  217.07
```

```
SCAN # 8
 1  27.832
 2  45.449
 3  16452
 4  27.147
 5  27.612
 6  27.391
 7  29.627
 8  28.801
 9  31.847
10  43.796
11  36.526
12  46.532
13  32.689
14  36.208
15  41.021
16  31.072
17  42.625
18  27.758
19  1323.2
20  2.368
21  34.604
22  36.744
23  35.274
24  37.2
25  50.422
26  69.549
27  77.285
28  75.498
29  92.737
30  113.93
31  115.15
32  190.06
33  57.151
34  116.41
35  107.37
36  23.502
37  36.533
38  87.507
39  23.055
40  2.4701
41  22.737
42  23.289
43  23.153
44  13.754
45  254.67
```

```
SCAN # 9
 1  30.857
 2  46.724
 3 -14535
 4  29.69
 5  30.347
 6  33.103
 7  36.031
 8  33.111
 9  35.462
10  50.565
11  41.603
12  53.914
13  36.22
14  42.284
15  46.959
16  34.649
17  44.438
18  31.367
19  1516.4
20  2.3558
21  40.453
22  41.286
23  41.540
24  41.239
25  [illegible]
26  61.537
27  91.165
28  89.095
29  [illegible]
30  139.66
31  [illegible]
32  [illegible]
33  [illegible]
34  138.76
35  123.17
36  25.133
37  43.625
38  106.87
39  23.833
40  2.4690
41  23.441
42  24.505
43  24.367
44  16.877
45  292.86
```

```
SCAN # 10
 1  36.244
 2  49.847
 3  [illegible]
 4  33.473
 5  34.564
 6  34.632
 7  53.891
 8  45.382
 9  38.544
10  57.137
11  47.235
12  61.828
13  41.656
14  49.512
15  [illegible]
16  48.787
17  31.614
18  33.908
19  1706.4
20  2.4632
21  45.476
22  45.995
23  47.006
24  [illegible]
25  54.131
26  94.191
27  [illegible]
28  103.08
29  [illegible]
30  166.69
31  [illegible]
32  263.64
33  65.534
34  162.5
35  [illegible]
36  30.962
37  [illegible]
38  120.69
39  24.832
40  2.4697
41  24.464
42  26.107
43  26.011
44  30.594
45  330.24
```

```
SCAN # 11
 1  46.487
 2  46.493
 3  [illegible]
 4  50.752
 5  46.308
 6  41.973
 7  52.617
 8  56.547
 9  41.955
10  66.327
11  53.373
12  71.061
13  53.33
14  53.126
15  55.453
16  50.4
17  57.073
18  38.758
19  1901.3
20  2.4104
21  50.54
22  51.333
23  [illegible]
24  47.721
25  [illegible]
26  107.79
27  125.63
28  117.69
29  146.22
30  194.04
31  166.66
32  239.63
33  64.309
34  182.98
35  153.43
36  41.464
37  53.613
38  130.19
39  26.142
40  2.4694
41  25.892
42  28.265
43  25.168
44  25.295
45  363.64
```

```
SCAN # 12
 1  53.562
 2  62.227
 3  12484
 4  52.541
 5  57.644
 6  53.585
 7  53.672
 8  57.79
 9  47.612
10  78.193
11  59.26
12  82.236
13  62.953
14  73.765
15  67.594
16  71.013
17  67.057
18  46.955
19  2019.2
20  2.4175
21  56.223
22  56.869
23  55.473
24  55.758
25  [illegible]
26  121.17
27  140.73
28  134.62
29  [illegible]
30  224.09
31  213.47
32  325.04
33  66.546
34  213.86
35  165.13
36  58.277
37  55.251
38  130.2
39  27.353
40  2.4693
41  27.724
42  31.035
43  30.9
44  31.138
45  411
```

```
SCAN # 13
 1  73.577
 2  75.589
 3 -38386
 4  68.329
 5  66.725
 6  69.05
 7  82.067
 8  80.951
 9  65.066
10  83.526
11  63.958
12  89.165
13  71.231
14  110.7
15  73.112
16  87.095
17  79.755
18  62.979
19  2542.9
20  2.4241
21  61.953
22  62.686
23  67.29
24  73.377
25  81.563
26  133.35
27  178.59
28  160.59
29  166.36
30  253.92
31  240.65
32  353.65
33  66.661
34  243.18
35  175.61
36  59.899
37  64.674
38  203.13
39  30.286
40  2.4691
41  30.11
42  34.41
43  34.376
44  36.245
45  453.42
```

```
SCAN # 14
 1  81.162
 2  76.6
 3 -1412.7
 4  71.734
 5  78.005
 6  77.444
 7  84.721
 8  85.444
 9  64.497
10  87.039
11  88.857
12  93.791
13  71.263
14  115.8
15  73.973
16  93.273
17  90.123
18  67.604
19  2041.3
20  2.4252
21  61.164
22  61.255
23  66.848
24  69.51
25  80.895
26  139.73
27  164.65
28  167.92
29  193
30  235.07
31  243.16
32  359.08
33  69.746
34  248.72
35  160.17
36  59.57
37  68.434
38  196.17
39  30.649
40  2.4692
41  30.572
42  33.863
43  33.929
44  33.884
45  460.96
```

```
SCAN # 15
 1  76.232
 2  68.509
 3  [illegible]
 4  72.777
 5  70.737
 6  73.309
 7  74.317
 8  78.875
 9  72.531
10  94.560
11  78.434
12  103.59
13  64.895
14  105.25
15  86.222
16  89.666
17  73.335
18  63.867
19  3056.9
20  2.4266
21  59.001
22  53.689
23  64.117
24  64.239
25  74.297
26  145.2
27  178.39
28  164.57
29  191.34
30  265.36
31  248.44
32  345.38
33  66.585
34  249.66
35  164.05
36  58.044
37  61.854
38  179.87
39  31.207
40  2.4692
41  31.168
42  33.067
43  33.714
44  33.122
45  470.89
```

```
SCAN # 16
 1  96.799
 2  84.834
 3  13977
 4  104.65
 5  101.48
 6  99.854
 7  92.736
 8  97.24
 9  91.326
10  107.53
11  105.41
12  120.86
13  73.573
14  112.2
15  107.61
16  114.61
17  84.001
18  92.13
19 -15018
20  2.433
21  65.47
22  66.399
23  67.327
24  78.534
25  85.184
26  167.68
27  193.38
28  182.38
29  206.79
30  296.14
31  275.11
32  394.8
33  72.975
34  273.85
35  170.25
36  64.395
37  67.99
38  192.37
39  34.44
40  2.4693
41  34.508
42  40.376
43  40.69
44  43.036
45  515.22
```

```
SCAN # 17
 1  100.4
 2  86.332
 3 -1527
 4  107.66
 5  104.76
 6  102.66
 7  95.961
 8  100.36
 9  102.04
10  119.65
11  113.09
12  128.31
13  76.613
14  114.6
15  [illegible]
16  118.15
17  85.654
18  97.55
19 -10149
20  2.4341
21  65.163
22  65.571
23  64.936
24  79.365
25  85.544
26  168.91
27  195.45
28  183.81
29  207.43
30  301.23
31  279.42
32  399.26
33  73.74
34  277.73
35  174.62
36  64.507
37  64.526
38  191.47
39  34.796
40  2.4693
41  35.121
42  41.196
43  40.691
44  35.564
45  522.77
```

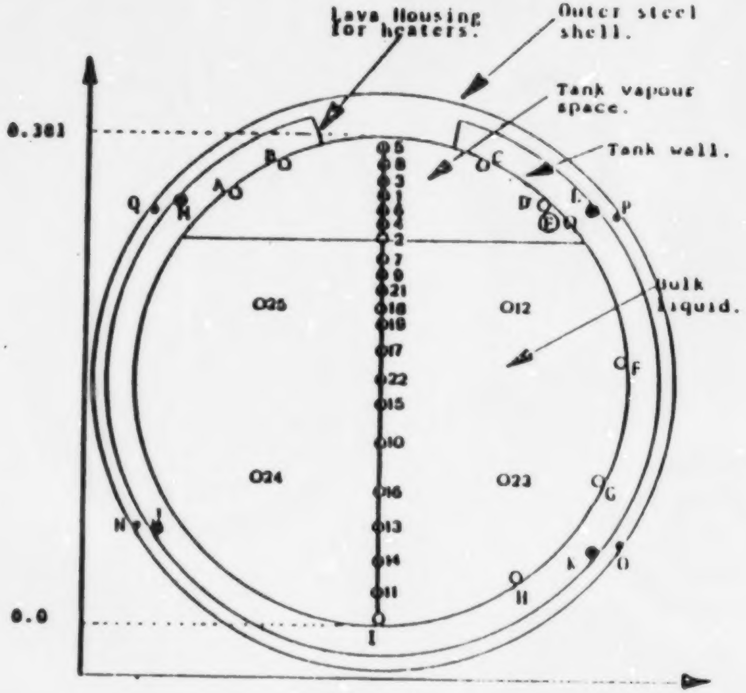
```
SCAN # 18
 1  98.823
 2  82.369
 3  16254
 4  104.39
 5  101.45
 6  97.356
 7  91.127
 8  96.267
 9  100.85
10  111.61
11  106.09
12  113.3
13  70.61
14  109.68
15  [illegible]
16  113.33
17  88.12
18  95.966
19 -10400
20  2.4348
21  62.166
22  62.446
23  61.515
24  72.516
25  80.231
26  164.71
27  191.67
28  176.37
29  200.91
30  305.88
31  282.7
32  402.96
33  72.471
34  278.57
35  171.01
36  62.812
37  61.749
38  184.06
39  35.234
40  2.4692
41  35.56
42  41.805
43  41.5
44  32.083
45  528.51
```

```
SCAN # 19
 1  67.941
 2  73.143
 3  32561
 4  93.773
 5  90.465
 6  88.683
 7  76.512
 8  85.78
 9  93.821
10  105.78
11  101.76
12  109.37
13  66.562
14  100.71
15  105.33
16  104.42
17  73.645
18  90.509
19 -6670.3
20  2.436
21  61.264
22  62.132
23  63.34
24  64.663
25  75.565
26  135.62
27  186.44
28  172.43
29  176.21
30  311.3
31  267.9
32  408.36
33  74.336
34  280.04
35  [illegible]
36  61.336
37  63.551
38  181.77
39  35.964
40  2.4693
41  36.365
42  42.815
43  42.472
44  36.93
45  537.83
```

```
SCAN # 20
 1  68.452
 2  73.207
 3  [illegible]
 4  95.782
 5  91.619
 6  89.453
 7  73.653
 8  65.702
 9  96.326
10  114.94
11  107.73
12  110.89
13  66.73
14  100.02
15  111.78
16  104.02
17  73.162
18  94.951
19  [illegible]
20  2.437
21  61.456
22  61.685
23  61.07
24  68.379
25  74.101
26  137.86
27  189
28  173.16
29  199.34
30  316.41
31  292.11
32  412.41
33  [illegible]
34  284.51
35  [illegible]
36  61.379
37  60.941
38  182.36
39  36.573
40  2.4691
41  37.852
42  43.787
43  43.326
44  37.044
45  548.54
```

```
SCAN # 21   SCAN # 22   SCAN # 23   SCAN # 24

 1   65.566   1   36.384   1   67.508   1   91.422
 2   63.336   2   71.816   2   69.176   2   72.574
 3 -70435     3   35255    3   31636    3 -1176.2
 4   92.11    4   96.605   4   94.571   4   99.39
 5   68.745   5   33.07    5   70.981   5   95.849
 6   66.651   6   30.015   6   88.503   6   93.283
 7   76.85    7   75.637   7   78.868   7   81.567
 8   82.706   8   85.43    8   84       8   87.247
 9   97.112   9  102.23    9   99.896   9  105.99
10    112.31 10    120.66 10    114.84 10    125.68
11    106.64 11    112.93 11    109.74 11    118.38
12    114.78 12    124.94 12    117.45 12    129.81
13   64.973  13   66.138  13   64.448  13   66.407
14   95.595  14   97.706  14   95.777  14   98.619
15   110.8   15   117.32  15   113.73  15   123
16   99.941  16   101.99  16   99.789  16   103.04
17   70.46   17   71.532  17   67.288  17   71.035
18   92.354  18   96.537  18   96.659  18   101.8
19   4371.6  19   4494    19   4438.5  19   4756.6
20   2.4381  20   2.4391  20   2.4403  20   2.4412
21   60.154  21   60.79   21   59.679  21   60.233
22   61.375  22   60.927  22   60.881  22   60.329
23   62.693  23   62.731  23   62.97   23   63.456
24   66.608  24   67.925  24   66.444  24   68.057
25   71.336  25   71.547  25   70.831  25   70.623
26   156.21  26   161.17  26   161.19  26   166.02
27   182.38  27   193.96  27   194.38  27   195.85
28   174.76  28   179.39  28   179.67  28   184.35
29   199.39  29   205.13  29   205.2   29   211.84
30   322.56  30   327.61  30   333.49  30   338.67
31   297.02  31   301.16  31   305.93  31   309.81
32   418.42  32   422.97  32   428.01  32   432.39
33   75.117  33   76.16   33   78.17   33   78.524
34   288.43  34   293.61  34   297.45  34   302.78
35   174.38  35   173.19  35   176.91  35   176.39
36   60.791  36   60.961  36   60.435  36   60.718
37   64.913  37   60.341  37   62.445  37   59.628
38   184.39  38   186.64  38   186.82  38   191.92
39   37.753  39   36.01   39   38.733  39   35.401
40   2.4692  40   2.4693  40   2.4693  40   2.4694
41   37.654  41   36.563  41   39.461  41   40.225
42   44.772  42   45.685  42   46.805  42   47.773
43   44.354  43   45.248  43   46.33   43   47.242
44   36.824  44   30.214  44   35.345  44   29.338
45   554.86  45   562.57  45   571.88  45   579.59
```



SYMBOL	Thermocouple #	Angle(Deg)
A	28	310
B & C	37 & 29	340 & 22
D & E	36 & 34	55 & 56
F & G	27 & 38	92 & 116
H & I	35 & 26	144 & 180
J & K	30 & 31	133 & 220
L & M	32 & 33	50 & 300
N & O	42 & 43	140 & 230
P & Q	39 & 41	60 & 310

○Circled thermocouple is inserted inside the vapour space wall.

Number 45 represents time in seconds.
Number 44 represents pressure in psig.
Reference upper diameter = 48.37 cms.

Thermocouple numbers.	Height (cm)	Angle with the vertical (Deg.)	Doubtful or faulty Thermocouple.
05	45.88	-	-
08	44.905	-	-
03	43.63	-	YES
01	42.715	-	-
06	41.805	-	-
04	40.745	-	-
02	39.885	-	-
07	37.765	-	-
09	36.845	-	-
21	35.705	-	-
18	34.84	-	-
19	33.86	-	YES
17	31.72	-	-
22	29.635	-	-
15	27.665	-	-
10	25.585	-	-
16	24.585	-	-
13	21.02	-	-
14	16.94	-	-
11	12.81	-	-
26	10.255	180	-
29 & 36	-	22 & 55	-
28 & 37	-	310 & 340	-
27 & 38	-	92 & 116	-
35	-	144	-
30 & 31	-	133 & 220	-
32 & 33	-	50 & 300	-
39 & 41	-	60 & 310	-
42 & 43	-	140 & 230	-
34	-	56	YES
23 & 25	-	-	YES
12	32.20	-	-
24	24.85	-	-
20 & 40	Reference temperature	-	-

Fig. III.B A grid layout of thermocouples along with their locations for an unprotected vessel(UNB) with the PRV orifice of 3/8 in. (Valid for 76, 58 and 23 percent liquid full cases)

RUN NUMBER 4

Q_{IN} = 65 KW/m^2, Set pressure of the PRV=35 psig.

Liquid level = 76% (58 deg. with the vertical)

PRV orifice diameter = 3/8 in.

No internal protection.

```
SCAN # 1        SCAN # 2        SCAN # 3        SCAN # 4        SCAN # 5        SCAN # 6        SCAN # 7        SCAN # 8        SCAN # 9         SCAN # 10

 1  22.456       1  23.646       1  25.395       1  28.113       1  30.542       1  35.269       1  39.986       1  44.736       1  49.716        1  52.329
 2  22.452       2  23.967       2  25.758       2  28.309       2  31.33        2  34.185       2  37.355       2  43.372       2  45.279        2  49.273
 3  656.77       3  835.77       3  1011.6       3  1126.6       3  1306.9       3  1501.3       3  1721.9       3  1950         3  2135.[illegible] 3  2134.[illegible]
 4  22.658       4  23.318       4  26.058       4  28.357       4  31.087       4  34.426       4  38.245       4  42.132       4  46.756        4  51.747
 5  22.563       5  23.597       5  25.886       5  30.526       5  33.125       5  40.564       5  47.275       5  53.233       5  60.555        5  61.955
 6  22.658       6  23.694       6  25.665       6  28.333       6  30.869       6  34.45        6  38.245       6  42.274       6  47.068        6  51.91
 7  22.575       7  23.003       7  24.46        7  27.331       7  29.604       7  32.856       7  36.712       7  39.896       7  44.973        7  48.569
 8  22.683       8  23.572       8  25.567       8  29.431       8  33.678       8  38.125       8  43.584       8  49.154       8  55.157        8  60.014
 9  22.535       9  23.005       9  24.465       9  27.386       9  29.336       9  32.736       9  36.375       9  39.61        9  44.9          9  46.554
10    22.465    10    22.811    10    23.105    10    25.836    10    27.798    10    32.227    10    33.799    10    36.906    10    40.373     10    44.478
11    22.436    11    22.758    11    23.228    11    24.632    11    26.771    11    29.044    11    31.767    11    34.622    11    38.249     11    42.131
12    22.559    12    22.733    12    24.091    12    26.425    12    28.727    12    31.5      12    34.667    12    38.654    12    42.439     12    47.468
13    22.468    13    22.709    13    23.006    13    24.115    13    26.62     13    30.602    13    32.736    13    35.778    13    39.014     13    44.225
14    22.46     14    22.585    14    22.957    14    24.139    14    26.28     14    28.946    14    32.179    14    35.88     14    38.057     14    41.92
15    22.51     15    22.536    15    23.302    15    26.234    15    28.848    15    32.542    15    35.558    15    37.721    15    41.23      15    45.398
16    22.51     16    22.61     16    23.154    16    24.927    16    27.53     16    32.227    16    33.509    16    36.69     16    40.278     16    44.36
17    22.495    17    22.96     17    23.746    17    26.988    17    29.336    17    32.663    17    36.207    17    39.624    17    44.548     17    49.383
18    22.559    18    23.03     18    24.465    18    27.184    18    29.117    18    32.736    18    36.375    18    39.8      18    44.477     18    48.524
19    891.73    19    912.77    19    945.61    19    1077.8    19    1161.9    19    1307.9    19    1456.9    19    1601      19    1782.1     19    1971.1
20    2.7134    20    2.7135    20    2.7136    20    2.7135    20    2.7138    20    2.7138    20    2.7139    20    2.7141    20    2.7142     20    2.7143
21    22.91     21    23.474    21    24.928    21    27.82     21    29.653    21    33.232    21    36.680    21    40.539    21    44.607     21    49.13
22    22.93     22    22.98     22    23.869    22    26.964    22    30.018    22    33.122    22    36.544    22    39.951    22    44.666     22    46.034
23    -227.27   23    1776.8    23    3722.8    23    4227.6    23    -290.11   23    1465.7    23    14.691    23    1159      23    1789.1     23    1769.1
24    23.004    24    23.03     24    23.721    24    26.964    24    28.727    24    31.184    24    35.847    24    37.745    24    41.895     24    45.186
25    -1775.3   25    1723.8    25    1716.8    25    3719.8    25    1210.9    25    1906.9    25    -1650.1   25    -2231     25    -1[illegible]9 25  [illegible]
26    23.22     26    25.656    26    27.143    26    28.453    26    31.437    26    34.315    26    36.843    26    33.994    26    43.7[illegible] 26  47.339
27    23.276    27    25.559    27    26.635    27    28.78     27    31.61     27    35.305    27    36.753    27    42.128    27    46.426     27    50.[illegible]
28    23.026    28    26.32     28    33.126    28    42.869    28    52.351    28    63.775    28    75.919    28    88.312    28    100.49     28    [illegible].69
29    23.146    29    26.563    29    33.166    29    41.726    29    52.54     29    55.687    29    75.838    29    94.555    29    [illegible] 29    [illegible]
30    24.716    30    24.62     30    32.838    30    46.631    30    64.506    30    85.703    30    108.46    30    132.8     30    [illegible] 30    133.99
31    23.335    31    27.834    31    36.44     31    50.119    31    66.647    31    86.073    31    107.14    31    127.51    31    [illegible] 31    [illegible]
32    23.026    32    29.685    32    46.309    32    70.21     32    93.614    32    116.61    32    143.67    32    164.51    32    197.33     32    [illegible].65
33    23.567    33    32.319    33    43.49     33    67.332    33    86.813    33    111.63    33    136.08    33    160.79    33    163.64     33    [illegible]
34    23.161    34    26.334    34    32.684    34    39.305    34    45.817    34    82.918    34    59.653    34    66.492    34    73.957     34    73.605
35    23.567    35    26.062    35    27.49     35    29.262    35    38.68     35    34.469    35    37.704    35    41.29     35    45.344     35    49.621
36    22.987    36    25.849    36    31.225    36    38.484    36    47.95     36    56.332    36    66.359    36    77.053    36    87.963     36    98.778
37    23.258    37    27.412    37    34.525    37    43.087    37    54.466    37    66.66     37    79.535    37    93.559    37    107.47     37    [illegible].13
38    23.21     38    25.772    38    27.413    38    28.877    38    31.437    38    34.679    38    37.818    38    41.981    38    45.819     38    49.594
39    -12.425   39    49.613    39    12.527    39    -38.654   39    43.784    39    32.417    39    -6.4346   39    56.163    39    [illegible] 39    5.6225
40    2.6795    40    2.6795    40    2.6796    40    2.6795    40    2.6797    40    2.6797    40    2.6798    40    2.6797    40    2.6799     40    2.6601
41    22.637    41    22.637    41    22.756    41    22.852    41    23.163    41    23.906    41    24.46     41    25.633    41    [illegible] 41    [illegible]
42    22.65     42    22.91     42    22.93     42    23.607    42    23.163    42    23.512    42    24.055    42    24.846    42    26.93      42    [illegible]
43    22.716    43    22.716    43    22.736    43    22.852    43    23.165    43    23.569    43    24.345    43    25.436    43    26.935     43    28.746
44    -.02578   44    .52849    44    1.6843    44    3.1489    44    4.9524    44    7.2668    44    16.394    44    14.106    44    18.662     44    24.263
45    6.468     45    42.611    45    79.365    45    115.66    45    151.71    45    188.02    45    224.23    45    260.77    45    297.94     45    334.[illegible]
```

```
SCAN # 11       SCAN # 12       SCAN # 13       SCAN # 14       SCAN # 15       SCAN # 16

 1  60.771       1  56.721       1  56.817       1  57.861       1  69.537       1  60.934
 2  53.816       2  59.566       2  56.156       2  54.805       2  63.107       2  61.33
 3  2062.1       3  2956.3       3  2242.3       3  2375.3       3  2806.5       3  2472.5
 4  57.098       4  61.46        4  54.491       4  57.538       4  66.739       4  59.427
 5  73.029       5  61.577       5  53.239       5  57.677       5  67.305       5  58.631
 6  57.444       6  63.626       6  54.121       6  58.137       6  67.439       6  59.611
 7  53.536       7  59.491       7  54.325       7  53.255       7  62.656       7  59.863
 8  67.861       8  75.776       8  53.262       8  57.815       8  77.513       8  58.991
 9  53.097       9  58.907       9  53.842       9  54.723       9  62.195       9  59.23
10    48.549    10    52.31     10    54.097    10    53.796    10    61.282    10    60.273
11    46.342    11    49.979    11    51.705    11    54.074    11    58.233    11    58.716
12    53.399    12    56.234    12    55.763    12    54.306    12    61.647    12    61.122
13    46.483    13    50.376    13    51.239    13    53.75     13    57.773    13    58.601
14    45.754    14    49.359    14    51.193    14    53.773    14    57.704    14    59.186
15    49.579    15    53.642    15    56.234    15    54.236    15    61.944    15    60.687
16    48.01     16    51.682    16    53.842    16    53.796    16    59.473    16    59.484
17    50.7      17    55.555    17    54.815    17    54.375    17    61.899    17    59.977
18    53.236    18    58.757    18    54.263    18    54.504    18    61.053    18    59.404
19    2173.2    19    2341.3    19    2221.3    19    2232.3    19    2503.5    19    2443.5
20    2.7145    20    2.7148    20    2.7148    20    2.7148    20    2.7153    20    2.7153
21    53.724    21    59.331    21    54.398    21    55.116    21    62.013    21    59.702
22    50.933    22    55.393    22    55.347    22    54.639    22    61.03     22    60.367
23    256.18    23    1429.3    23    572.3     23    1169.3    23    749.5     23    557.5
24    49.836    24    53.216    24    56.109    24    54.931    24    60.298    24    60.413
25    11509     25    -3205.7   25    3716.3    25    -7.7035   25    311.3     25    1839.5
26    51.581    26    58.453    26    53.907    26    57.676    26    63.789    26    60.33
27    55.465    27    60.667    27    54.839    27    58.41     27    65.452    27    60.048
28    123.33    28    133.92    28    56.754    28    92.889    28    130.01    28    62.246
29    137.57    29    150.66    29    54.548    29    85.466    29    152.4     29    60.142
30    209.89    30    236.3     30    241.42    30    247.72    30    277.59    30    282.86
31    201.13    31    226.17    31    238.72    31    236.45    31    261.11    31    265.67
32    247.02    32    270.32    32    273.32    32    280.92    32    308.14    32    312.48
33    229.78    33    251.63    33    255.85    33    250.68    33    285.78    33    290.39
34    82.723    34    85.543    34    54.456    34    59.896    34    85.304    34    55.884
35    53.414    35    58.513    35    54.152    35    58.166    35    64.74     35    60.185
36    189.71    36    120.56    36    56.094    36    83.652    36    126.82    36    60.988
37    135.03    37    140.65    37    62.112    37    101.32    37    157.74    37    62.752
38    54.263    38    58.316    38    54.265    38    58.316    38    65.246    38    59.936
39    16.535    39    -10.421   39    175.82    39    -12967    39    -32.844   39    38.361
40    2.6002    40    2.6004    40    2.6004    40    2.6004    40    2.6006    40    2.6006
41    31.538    41    34.435    41    35.188    41    35.855    41    40.117    41    40.859
42    28.999    42    31.021    42    31.444    42    31.924    42    34.823    42    35.378
43    31        43    33.786    43    34.32     43    35.089    43    39.829    43    39.733
44    31.181    44    39.779    44    23.852    44    30.292    44    42.176    44    29.859
45    372.44    45    411.69    45    418.62    45    427.84    45    472.27    45    480.16
```

RUN NUMBER 5

Q_{IN} = 65 KW/m^2, Set pressure of the PRV = 35 psig.

Liquid level = 58% (81 deg. with the vertical)

PRV orifice diameter = 3/8 in.

No internal protection.

	SCAN # 1	SCAN # 2	SCAN # 3	SCAN # 4	SCAN # 5	SCAN # 6	SCAN # 7	SCAN # 8	SCAN # 9	SCAN # 10
1	18.669	18.855	19.636	21.362	23.474	25.382	28.213	33.377	42.179	54.011
2	18.645	18.93	19.959	21.436	24.016	26.658	32.13	37.132	47.631	60.802
3	737.94	745.39	766.8	875.32	964.77	1051.3	1163.9	1318.4	1507	1542.6
4	18.694	18.93	19.81	21.889	22.956	25.807	26.848	37.3	40.636	39.199
5	18.794	18.979	19.587	21.659	23.4	24.768	26.659	28.52	31.357	40.026
6	18.694	18.88	19.761	21.362	23.133	25.21	28.36	35.475	45.137	50.281
7	18.645	19.054	20.332	21.287	22.165	24.768	28.287	33.86	40.134	40.371
8	18.769	18.93	19.587	22.796	24.601	26.588	28.287	30.663	33.415	42.382
9	18.645	19.079	20.406	21.788	23.794	26.34	28.14	30.323	35.561	41.1
10	18.445	18.531	18.865	19.401	20.803	23.506	26.525	30.88	34.525	38.907
11	18.296	18.387	18.417	18.554	19.808	19.848	21.425	23.219	25.490	28.572
12	18.794	19.253	20.53	22.855	23.77	27.417	31.354	37.812	43.88	49.167
13	18.42	18.456	18.491	19.803	19.909	21.609	23.969	27.298	30.896	34.868
14	18.37	18.487	18.467	18.754	19.263	20.444	22.439	24.82	27.997	31.415
15	18.445	18.481	19.114	21.168	23.351	26.34	28.945	33.063	36.578	40.866
16	18.445	18.556	18.741	19.276	20.679	23.29	26.353	29.989	34.891	38.357
17	18.545	18.979	19.935	21.659	23.72	26.83	30.115	34.464	35.893	43.531
18	18.645	19.129	20.085	22.253	23.794	25.873	28.091	31.537	37.026	42.599
19	733.94	763.39	816.8	881.32	957.77	1005.3	1202.9	1383.4	1642	1636.6
20	2.4119	2.413	2.414	2.4153	2.4164	2.4177	2.4191	2.4205	2.4219	2.4233
21	19.236	19.726	21.175	22.673	25.074	27.319	28.58	31.416	37.29	44.111
22	19.118	19.477	19.788	22.805	23.967	27.172	29.969	34.343	38.654	43.567
23	-13295	44825	9401.8	-13356	-27621	115438	73203	-46441	-28949	-32158
24	19.060	19.203	19.537	20.171	22.066	24.989	28.14	31.929	38.87	40.497
25	-44077	-30602	-35162	-30462	-54788	-22762	1120.9	119840	-23966	-15615
26	18.224	18.723	19.495	20.231	20.943	22.453	24.896	25.872	[illegible]	30.857
27	18.666	20.213	24.625	30.741	36.545	42.519	50.559	58.217	66.485	73.135
28	18.902	20.821	25.366	33.965	43.868	59.199	76.982	97.137	119.77	145.37
29	19.002	21.616	27.547	35.405	51.187	69.49	92.27	118.71	147.43	173.53
30	19.113	19.989	24.806	37.201	52.832	75.868	102.7	131.88	162.44	193.57
31	19.352	21.403	27.316	39.34	53.493	73.595	95.308	118.27	142.27	164.1
32	18.524	22.76	34.65	55.084	74.809	100.77	127.33	156.34	186.54	216.83
33	19.116	22.779	32.741	38.267	69.806	93.878	120.17	147.19	174.87	205.03
34	19.138	21.635	26.138	34.349	43.431	57.186	74.487	94.685	118.45	141.37
35	18.613	20.045	21.824	23.894	25.319	20.268	28.863	30.881	33.912	37.65
36	19.177	20.841	24.535	31.413	39.01	58.163	63.347	78.319	94.794	107.96
37	19.455	22.469	28.538	38.806	49.92	66.048	85.15	106.77	130.73	147.66
38	18.807	20.864	21.126	22.52	24.468	26.05	29.383	32.872	35.751	39.895
39	1417	131.5	-9073	17.139	-12396	-63443	-60496	-91174	-139740	-1092.3
40	2.356	2.3573	2.3587	2.3604	2.3617	2.3634	2.3651	2.3668	2.3685	2.3702
41	19.818	19.831	19.787	19.92	19.933	20.848	20.142	20.159	20.06	20.038
42	20.129	20.142	20.156	20.192	20.283	20.514	20.977	21.75	22.911	24.476
43	19.618	19.812	19.826	19.901	20.869	20.514	21.266	22.429	24.814	26.253
44	.40553	.80778	1.7316	2.9003	4.1240	5.9555	8.2754	11.189	14.806	19.168
45	8.404	38.531	60.841	105.12	137.78	177.66	216.81	260.59	303.16	346.49

	SCAN # 11	SCAN # 12	SCAN # 13	SCAN # 14	SCAN # 15	SCAN # 16	SCAN # 17	SCAN # 18	SCAN # 19	SCAN # 20
1	77.456	81.964	88.105	87.5	66.397	109.65	106.44	[illegible]	116.57	128.23
2	64.474	65.505	71.237	72.315	60.319	93.674	94.583	69.673	107.4	107.76
3	2299.1	2734.7	3993.2	3808.3	2753.4	5032.9	4614	5242.1	6074.6	5724.7
4	63.613	69.788	74.816	74.773	62.216	97.566	96.435	71.371	112.61	110.32
5	73.742	101.57	120.23	99.814	61.439	133.97	116.21	74.834	155.45	131.24
6	63.234	76.905	81.707	79.679	65.332	104.34	108.44	73.989	121.24	114.95
7	77.873	56.141	62.416	63.216	56.181	88.467	80.05	62.724	91.569	90.335
8	71.795	94.467	107.27	90.304	65.74	124.65	107.29	77.35	147.53	122
9	65.633	55.841	62.599	61.525	54.47	74.431	73.848	55.776	62.751	61.455
10	43.72	40.42	53.678	56.063	49.23	56.908	55.388	52.12	60.494	58.629
11	31.674	34.655	58.969	35.735	48.906	49.082	50.137	51.617	52.962	53.203
12	56.427	63.27	69.642	52.612	53.149	73.917	56.173	55.885	79.167	74.516
13	38.584	42.622	46.672	49.732	49.046	53.347	55.526	52.027	59.132	56.334
14	34.816	38.694	42.705	43.915	48.812	51.836	53.906	51.748	55.353	57.226
15	45.943	50.361	55.576	55.37	49.865	57.392	54.879	52.887	61.512	57.779
16	42.844	47.787	51.493	55.416	49.491	56.608	54.405	52.19	60.598	57.318
17	43.622	53.967	59.925	54.352	51.088	58.289	54.115	53.615	62.106	57.627
18	49.366	58.949	65.441	56.363	53.381	63.868	54.532	56.152	78.461	60.393
19	2053.1	2321.7	2613.2	2066.3	2103.4	2547.9	2142	2301.1	2706.6	2202.7
20	2.4249	2.426	2.4273	2.4275	2.4270	2.4291	2.4294	2.4296	2.4308	2.4311
21	40.892	60.325	67.681	63.625	54.331	72.755	64.898	56.913	77.847	66.933
22	40.531	53.921	59.947	55.993	51.125	58.565	53.512	53.792	62.608	57.253
23	380100	41602	89684	-576630	-197900	9606.9	-12404	-120418	-178050	-25399
24	45.863	58.811	55.16	52.286	50.822	57.115	54.522	53.073	60.392	57.802
25	-28398	11550	29975	-131940	21577	410290	195030	58667	151820	53575
26	33.945	37.1	41.087	41.508	47.384	50.697	51.802	53.424	55.654	55.122
27	78.986	82.635	66.824	45.826	54.628	76.318	52.456	58.05	53.755	56.73
28	167.06	174.81	188.36	178.92	170.81	201.17	194.72	146.27	225.45	216.52
29	237.07	219.78	236.41	231.53	221	257.05	253.83	249.06	290.33	265.62
30	224.1	255	205.71	290.74	296.69	325.55	330.44	336.26	364.7	360.93
31	138.41	213.53	224.73	242.25	234.94	263.76	265.28	259.55	283.33	276.69
32	245.62	273.69	301.7	305.3	310.89	334.02	339.19	345.71	366.21	372.21
33	229.02	257	287.51	290.71	296.16	322.3	326.59	332.22	356	359.41
34	140.24	171.76	188.75	180.73	173.84	200.74	196.15	191.3	224.23	216.29
35	44.674	44.857	49.331	47.249	52.514	57.359	52.156	56.385	61.291	55.763
36	126.64	146.66	165.97	151.98	146.49	179.36	166.27	168.97	201.01	185.37
37	169.7	181.9	199.49	183.2	170.66	219.35	205.73	203.66	246.11	229.72
38	43.891	40.538	53.774	48.235	52.741	59.09	52.288	56.14	62.774	56.083
39	-443344	-441570	238990	-173040	157110	-149830	147.39	141810	-165330	1150000
40	2.3719	2.3734	2.3751	2.3753	2.3756	2.3773	2.3776	2.3779	2.3795	2.3798
41	20.122	20.286	20.184	21.039	20.985	20.739	21.568	21.416	21.102	42.404
42	25.462	28.965	33.897	32.617	33.311	37.843	37.734	38.539	43.016	43.78
43	28.737	31.773	35.781	36.089	36.95	41.014	41.798	43	47.764	48.733
44	26.199	30.992	39.983	18.532	25.123	35.405	21.342	28.251	39.707	25.837
45	380.73	434.44	466.65	487.69	496.86	541.9	349.89	558.95	604.66	612.17

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SCAN # 21    SCAN # 22    SCAN # 23    SCAN # 24    SCAN # 25    SCAN # 26    SCAN # 27    SCAN # 28    SCAN # 29    SCAN # 30

 1  62.756    1  143.69    1  141.48    1  67.459    1  97.716    1  78.053    1  157.82    1  162.07    1  165.27    1  167.62
 2  76.633    2  123.67    2  123.55    2  83.256    2  85.167    2  72.574    2  136.18    2  140.77    2  143.58    2  145.92
 3  3540.3    3  6575.3    3  6620.5    3  3752.6    3  4329.7    3  3268.2    3  7583.4    3  7797.4    3  7340.5    3  8066.5
 4  73.297    4  129.82    4  125.71    4  85.274    4  80.763    4  74.875    4  143.89    4  146.82    4  149.02    4  151.44
 5  76.655    5  174.3     5  144.6     5  85.755    5  100.26    5  76.477    5  190.91    5  193.51    5  154.35    5  156.73
 6  81.655    6  128.77    6  129.8     6  88.135    6  91.658    6  77.743    6  152.71    6  156.3     6  158.89    6  161.23
 7  63.656    7  164.41    7  102.05    7  75.538    7  75.741    7  67.695    7  114.53    7  118.6     7  121.75    7  124.33
 8  82.096    8  166.62    8  136.59    8  90.85     8  97.287    8  60.619    8  176.47    8  177.82    8  179.63    8  183.28
 9  65.908    9  94.697    9  92.519    9  68.785    9  71.647    9  61.541    9  103.83    9  107.21    9  110.62    9  112.46
10    55.613 10    63.945 10    62.88  10    59.269 10    58.606 10    56.491 10    62.99  10    63.948 10    64.494 10    65.312
11    55.313 11    57.378 11    57.542 11    58.764 11    59.604 11    56.306 11    58.345 11    58.347 11    58.784 11    59.175
12    59.435 12    87.323 12    78.931 12    63.041 12    59.249 12    61.083 12    94.115 12    96.932 12    102.46 12    105.38
13    55.452 13    60.869 13    63.579 13    58.947 13    58.812 13    56.26  13    62.329 13    63.675 13    62.263 13    63.221
14    55.29  14    59.355 14    61.395 14    58.718 14    59.547 14    56.053 14    59.653 14    60.457 14    61.121 14    61.648
15    56.752 15    65.036 15    61.715 15    60.002 15    58.675 15    57.275 15    63.764 15    64.524 15    65.373 15    66.266
16    55.621 16    63.832 16    61.761 16    59.292 16    58.215 16    56.353 16    62.944 16    63.834 16    64.562 16    65.335
17    64.63  17    65.128 17    61.281 17    63.723 17    58.261 17    60.214 17    70.635 17    72.229 17    73.55  17    74.712
18    59.664 18    79.858 18    70.256 18    63.246 18    57.525 18    59.779 18    81.865 18    86.211 18    89.113 18    91.61
19    2454.2 19    3180.1 19    2462.5 19    2612.6 19    2357.7 19    2450.8 19    3189.4 19    3335.4 19    3434.5 19    3519.5
20    2.4313 20    2.4326 20    2.4329 20    2.4332 20    2.4335 20    2.4338 20    2.4351 20    2.4353 20    2.4354 20    2.4355
21    60.42  21    80.152 21    73.572 21    64.133 21    60.944 21    60.535 21    94.611 21    90.354 21    101.87 21    103.48
22    57.297 22    66.879 22    60.801 22    60.643 22    58.767 22    58.88  22    64.65  22    65.9   22    66.172 22    67.237
23   -270450 23    139470 23    210650 23   -111190 23   -514480 23   -177760 23   -99295  23   -30603  23   -41357  23   -47531
24    56.744 24    65.013 24    61.052 24    60.46  24    58.801 24    57.915 24    63.65  24    64.084 24    65.107 24    65.637
25    263820 25   -135680 25    17592  25    906760 25    361140 25    158250 25    53768  25    38935  25   -3493.5 25   -4493.5
26    57.479 26    60.262 26    60.189 26    61.381 26    60.74  26    58.957 26    61.679 26    61.538 26    61.12  26    62.418
27    65.553 27    115.63 27    61.523 27    71.111 27    59.556 27    69.94  27    130.15 27    133.79 27    136.76 27    139.34
28    206.3  28    250.4  28    237.14 28    223.61 28    228.37 28    219.2  28    268.14 28    270.33 28    272.5  28    273.68
29    277.33 29    323.35 29    317.37 29    305.37 29    303.08 29    301.96 29    344.11 29    345.65 29    346.89 29    347.27
30    374.59 30    401.89 30    406.19 30    411.36 30    415.6  30    420.7  30    443.93 30    446.81 30    449.02 30    451.84
31    281.49 31    296.8  31    299.89 31    310.16 31    312.49 31    315.14 31    325.61 31    326.48 31    327.33 31    327.53
32    376.48 32    390.21 32    402.34 32    404.87 32    407.64 32    411.42 32    418.5  32    418.23 32    417.87 32    417.38
33    364.25 33    386.91 33    390.63 33    355    33    394.65 33    403.28 33    420.28 33    422.09 33    423.45 33    424.63
34    211.75 34    256.36 34    229.18 34    232.54 34    227.1  34    227.46 34    268.86 34    270.9  34    272.78 34    274.29
35    59.522 35    65.136 35    55.983 35    63.459 35    57.644 35    59.822 35    63.055 35    64.338 35    65.003 35    65.174
36    179.76 36    224.55 36    203.65 36    196.08 36    187.45 36    189.31 36    240.98 36    243.8  36    245.76 36    247.06
37    224.79 37    272.19 37    251.16 37    244.36 37    236.3  37    241.69 37    269.85 37    291.57 37    292.59 37    293.42
38    59.511 38    66.863 38    60.037 38    63.421 38    57.468 38    59.697 38    64.924 38    66.05  38    66.015 38    66.896
39   -460320 39   -432930 39   -104670 39    1916.4 39    1642.3 39   -145440 39   -241220 39   -20840  39   -76067  39    1377.4
40    2.38   40    2.3818 40    2.3821 40    2.3824 40    2.3827 40    2.383  40    2.3846 40    2.3849 40    2.3851 40    2.3853
41    21.766 41    21.435 41    23.898 41    22.137 41    23.646 41    22.63  41    21.948 41    21.951 41    21.956 41    21.638
42    44.732 42    58.822 42    50.876 42    51.9   42    52.791 42    53.87  42    59.894 42    60.874 42    61.702 42    62.53
43    49.672 43    55.349 43    56.313 43    57.164 43    58.089 43    59.221 43    65.242 43    66.237 43    67.026 43    67.813
44    32.754 44    45.695 44    29.329 44    37.704 44    25.909 44    32.612 44    40.814 44    42.873 44    43.083 44    44.127
45    621.67 45    664.31 45    676.82 45    685.31 45    693.82 45    702.28 45    749.71 45    757.26 45    763.51 45    769.74
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SCAN # 32    SCAN # 31

 1  171.83    1  169.31
 2  149.61    2  147.87
 3  6322.7    3  6179.6
 4  155.25    4  153.39
 5  203.26    5  199.16
 6  165.26    6  163.08
 7  122.47    7  126.52
 8  183.41    8  185.71
 9  116.71    9  114.78
10    65.314 10    65.949
11    59.645 11    59.476
12    110.3  12    108.29
13    63.59  13    63.189
14    61.515 14    62.083
15    67.377 15    66.718
16    65.385 16    65.881
17    76.831 17    75.85
18    95.739 18    93.775
19    3665.7 19    3596.6
20    2.436  20    2.4357
21    107.53 21    105.6
22    68.212 22    67.683
23   -45927  23   -50357
24    66.857 24    66.99
25   -1202.3 25   -5331.4
26    62.685 26    62.813
27    143.53 27    141.81
28    275.52 28    274.67
29    747.36 29    747.47
30    454.69 30    452.9
31    328.66 31    327.86
32    416.07 32    416.8
33    426.60 33    425.72
34    276.41 34    275.48
35    66.321 35    65.793
36    249.17 36    248.21
37    294.42 37    294.16
38    67.425 38    66.954
39    1799.3 39   -71561
40    2.3858 40    2.3854
41    21.863 41    21.879
42    64.167 42    63.375
43    69.447 43    66.618
44    46.839 44    45.154
45    782.37 45    776.14
```

RUN NUMBER 6

Q_{IN} = 65 KW/m^2, Set pressure of the PRV = 35 psig.

Liquid level = 23% (125 deg. with the vertical)

PRV orifice diameter = 3/8 in.

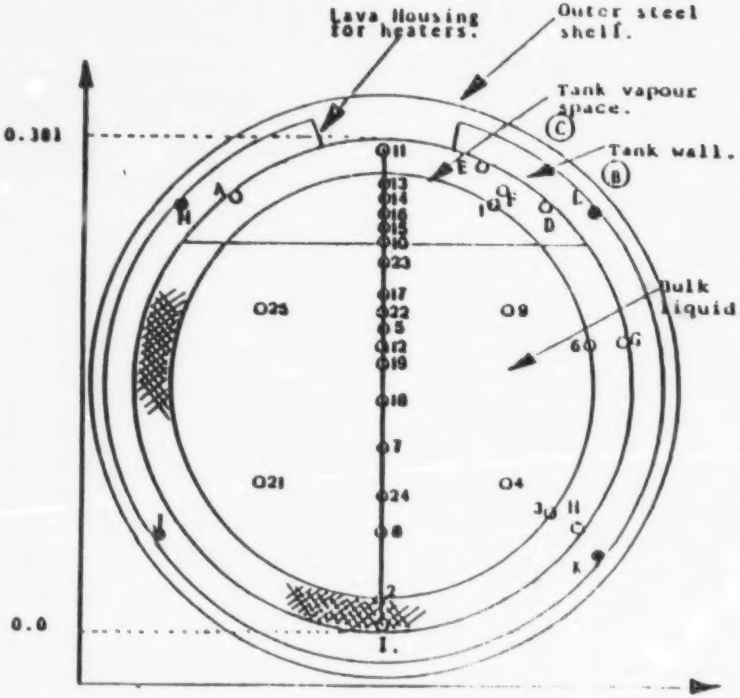
No internal protection.

```
SCAN # 1     SCAN # 2     SCAN # 3     SCAN # 4     SCAN # 5     SCAN # 6     SCAN # 7     SCAN # 8     SCAN # 9     SCAN # 10

 1 24.147     1 27.464     1 34.273     1 42.352     1 53.371     1 65.684     1 81.742     1 92.196     1 105.67     1 105.48
 2 23.013     2 25.933     2 31.539     2 40.165     2 50.018     2 61.748     2 72.55      2 84.664     2 95.736     2 96.556
 3 975.1      3 1131.7     3 1409.5     3 1797.3     3 2200       3 2815.9     3 3542.8     3 4042.7     3 4661.6     3 4566.7
 4 23.186     4 26.081     4 31.491     4 39.64      4 48.943     4 60.811     4 72.729     4 83.672     4 96.597     4 96.452
 5 24.851     5 29.389     5 35.838     5 42.613     5 51.408     5 67.463     5 85.431     5 97.822     5 103.16     5 102.65
 6 23.581     6 27.812     6 32.944     6 41.283     6 51.208     6 63.776     6 78.96      6 88.043     6 102.61     6 101.25
 7 22.741     7 25.467     7 30.787     7 38.563     7 46.216     7 58.909     7 68.689     7 86.285     7 90.275     7 91.054
 8 24.415     8 28.328     8 35.02      8 42.399     8 51.631     8 67.819     8 83.106     8 94.984     8 107.84     8 99.658
 9 22.544     9 25.025     9 29.765     9 36.625     9 45.49      9 58.462     9 64.795     9 76.718     9 87.612     9 87.615
10 22.140    10 23.547    10 26.614    10 31.849    10 39.108    10 47.206    10 56.166    10 64.68     10 73.262    10 72.504
11 22.325    11 24.286    11 27.545    11 43.132    11 39.064    11 45.158    11 51.949    11 58.926    11 65.971    11 62.938
12 23.036    12 25.467    12 30.276    12 37.872    12 49.411    12 62.387    12 73.668    12 85.622    12 96.231    12 94.964
13 22.445    13 24.262    13 27.569    13 32.63     13 33.968    13 44.675    13 52.111    13 59.201    13 66.424    13 60.606
14 22.643    14 24.311    14 27.887    14 33.035    14 38.845    14 45.816    14 51.949    14 58.857    14 66.016    14 61.972
15 22.198    15 23.646    15 27.153    15 33.591    15 41.609    15 49.993    15 59.903    15 69.427    15 77.405    15 76.652
16 22.198    16 23.621    16 26.59     16 31.687    16 37.313    16 45.794    16 54.456    16 62.723    16 70.977    16 70.014
17 22.346    17 24.286    17 28.937    17 35.423    17 44.357    17 54.459    17 64.432    17 74.871    17 84.967    17 84.146
18 22.445    18 24.902    18 29.644    18 36.961    18 45.843    18 56.677    18 66.88     18 77.672    18 89.102    18 87.135
19 645.1     19 960.75    19 1169.5    19 1441.3    19 1776      19 1234.9    19 2666.3    19 3133.7    19 3622.6    19 3544.7
20 2.3901    20 2.3917    20 2.3936    20 2.3955    20 2.3972    20 2.3995    20 2.4016    20 2.4078    20 2.4061    20 2.4064
21 23.136    21 25.516    21 30.325    21 37.8      21 46.737    21 57.345    21 66.812    21 75.493    21 90.571    21 86.673
22 22.665    22 24.459    22 28.791    22 35.327    22 43.719    22 52.882    22 62.657    22 72.055    22 81.452    22 73.49
23 30546     23 -29446    23 37328     23 35239     23 -25486    23 -238410   23 114910    23 231630    23 -249710   23 -56001
24 23.704    24 25.025    24 28.522    24 34.291    24 41.894    24 50.74     24 59.938    24 68.278    24 76.427    24 74.225
25 -20155    25 -14673    25 15397     25 20969     25 -26866    25 447180    25 67557     25 119630    25 35563     25 [illegible]
26 26.303    26 28.151    26 32.346    26 35.606    26 40.766    26 46.912    26 53.784    26 60.66     26 67.864    26 59.653
27 29.964    27 37.459    27 46.611    27 63.408    27 60.462    27 96.788    27 118.41    27 137.1     27 155.6     27 152.54
28 30.464    28 39.349    28 52.055    28 67.902    28 85.915    28 104.82    28 123.22    28 137.01    28 146.28    28 142.9
29 34.17     29 45.765    29 60.176    29 77.597    29 99.[illegible] 29 122.01  29 126.73    29 145.67    29 173.31    29 151.44
30 30.137    30 42.57     30 62.542    30 99.466    30 107.68    30 126.68    30 139.65    30 154.63    30 171.54    30 [illegible]
31 35.811    31 52.979    31 76.78     31 92.052    31 94.746    31 125.95    31 146.93    31 163.96    31 188.[illegible] 31 [illegible]
32 45.736    32 59.81     32 80.133    32 121.88    32 150.57    32 171.33    32 202.26    32 232.77    32 263.37    32 [illegible]
33 35.649    33 57.015    33 79.178    33 104.74    33 131.23    33 158.78    33 156.95    33 216.01    33 242.41    33 245.36
34 30.791    34 38.433    34 49.974    34 64.87     34 82.338    34 101.73    34 122.23    34 138.17    34 151.87    34 149.28
35 25.727    35 30.211    35 32.134    35 34.64     35 40.556    35 46.779    35 52.93     35 60.83     35 67.961    35 57.355
36 29.425    36 36.673    36 47.341    36 66.667    36 75.89     36 92.372    36 108.25    36 120.99    36 130.21    36 123.46
37 34.536    37 45.574    37 59.367    37 75.665    37 93.937    37 111.75    37 123.69    37 132.49    37 140.43    37 133.65
38 33.077    38 42.19     38 54.302    38 68.445    38 83.395    38 98.033    38 112.12    38 126.21    38 139.95    38 135.29
39 450.65    39 1349.7    39 61830     39 -17123    39 -71656    39 -334550   39 113620    39 325430    39 121660    39 -1150602
40 2.3326    40 2.3342    40 2.3363    40 2.3334    40 2.3405    40 2.3429    40 2.3447    40 2.3474    40 2.3453    40 2.3531
41 21.369    41 21.501    41 21.852    41 22.571    41 23.734    41 25.459    41 27.651    41 31.294    41 35.452    41 36.318
42 21.447    42 21.501    42 21.658    42 21.989    42 22.572    42 23.564    42 24.917    42 26.971    42 29.594    42 30.323
43 21.427    43 21.618    43 22.123    43 23.348    43 25.126    43 27.505    43 30.604    43 34.431    43 33.779    43 39.43
44 58665     44 1.4179    44 3.3643    44 6.3376    44 18.475    44 15.782    44 22.863    44 31.452    44 41.366    44 23.344
45 7.936     45 42.678    45 81.468    45 122.81    45 164.61    45 207.14    45 252.34    45 299.93    45 348.79    45 356.3


SCAN # 11    SCAN # 12    SCAN # 13    SCAN # 14    SCAN # 15    SCAN # 16    SCAN # 17    SCAN # 18    SCAN # 19    SCAN # 20

 1 75.125     1 108.27     1 108.51     1 77.572     1 113.45     1 113.95     1 92.016     1 121.66     1 123.15     1 84.348
 2 76.122     2 100.75     2 102.93     2 79.587     2 107.91     2 109.23     2 84.302     2 115.94     2 117.89     2 87.742
 3 2847.3     3 4677.7     3 4666.9     3 3173.1     3 4982.9     3 4971.1     3 3326.2     3 5410.1     3 5402.3     3 3629.4
 4 75.277     4 102.5      4 103.42     4 78.731     4 107.49     4 108.83     4 83.314     4 116.15     4 117.72     4 85.902
 5 65.902     5 118        5 108.94     5 68.402     5 117.56     5 115.11     5 66.787     5 124.93     5 123.05     5 87.228
 6 76.7       6 107.53     6 104.42     6 73.897     6 111.6      6 110.62     6 64.06      6 120.15     6 119.62     6 86.531
 7 74.133     7 95.433     7 96.388     7 76.262     7 102        7 103.22     7 61.928     7 111.71     7 112.98     7 85.362
 8 69.342     8 107.43     8 103.55     8 73.341     8 114.12     8 110.07     8 74.594     8 122.76     8 118.01     8 [illegible]
 9 71.562     9 91.023     9 91.678     9 74.123     9 97.312     9 98.635     9 78.382     9 105.74     9 107.37     9 82.435
10 63.775    10 72.383    10 73.89     10 64.695    10 75.878    10 74.903    10 65.169    10 82.256    10 82.636    10 69.409
11 55.972    11 64.431    11 61.542    11 51.641    11 64.481    11 61.067    11 51.168    11 65.235    11 61.619    11 59.742
12 79.736    12 95.668    12 97.097    12 80.912    12 101.76    12 102.93    12 65.803    12 109.65    12 110.32    12 91.032
13 55.532    13 65.371    13 59.73     13 55.713    13 67.335    13 66.549    13 62.736    13 72.692    13 73.412    13 67.03
14 54.134    14 64.749    14 60.765    14 53.026    14 64.935    14 59.67     14 52.959    14 66.368    14 60.43     14 52.490
15 66.272    15 78.668    15 73.648    15 65.711    15 81.679    15 78.635    15 67.727    15 87.734    15 64.15     15 72.653
16 63.206    16 63.609    16 70.355    16 63.463    16 74.497    16 71.482    16 63.169    16 80.095    16 79.524    16 67.821
17 65.335    17 86.864    17 85.587    17 71.834    17 91.922    17 90.582    17 74.616    17 95.964    17 97.964    17 78.465
18 72.373    18 90.921    18 90.834    18 74.435    18 96.13     18 95.64     18 77.885    18 102.94    18 101.69    18 81.492
19 2897.9    19 3655.7    19 3618.9    19 2900.1    19 3935.9    19 3920.1    19 3146.2    19 4281.1    19 4215.3    19 3304.4
20 2.4068    20 2.4009    20 2.4093    20 2.4099    20 2.4118    20 2.4123    20 2.4126    20 2.4148    20 2.4152    20 2.4155
21 72.739    21 92.524    21 98.1      21 74.944    21 99.006    21 96.006    21 76.638    21 106.12    21 101.96    21 82.44
22 68.215    22 81.256    22 79.759    22 68.875    22 96.549    22 83.465    22 71.395    22 93.851    22 91.41     22 75.89
23 -255730   23 -786650   23 366678    23 -687610   23 292450    23 114730    23 -487560   23 20099     23 147090    23 415330
24 67.38     24 77.164    24 75.633    24 67.521    24 81.172    24 79.587    24 70.43     24 86.663    24 83.974    24 72.631
25 447130    25 513650    25 41603     25 -424.67   25 10187     25 367230    25 346530    25 633360    25 -230840   25 -3895.6
26 56.343    26 66.358    26 57.501    26 54.638    26 66.275    26 56.589    26 53.803    26 67.54     26 56.394    26 53.587
27 149.63    27 174.11    27 171.53    27 169.58    27 195.75    27 192.56    27 189.84    27 217.68    27 214.37    27 210.34
28 133.85    28 151.32    28 147.45    28 138.88    28 159.77    28 154.32    28 144.99    28 168.82    28 162.79    28 151.51
29 145.35    29 156.35    29 155.36    29 148.81    29 162.14    29 160.68    29 153.26    29 167.52    29 165.72    29 157.5
30 176.69    30 152.28    30 194.64    30 137.6     30 218.14    30 211.71    30 213.63    30 221.46    30 222.49    30 223.7
31 157.44    31 153.97    31 151.27    31 152.58    31 161.16    31 160.5     31 161.5     31 166.74    31 166.64    31 166.07
32 272.43    32 331.69    32 388.88    32 311.72    32 338.97    32 343.25    32 340.27    32 373.87    32 376.85    32 381.51
33 250.25    33 271.97    33 273.81    33 276.63    33 292.78    33 294.14    33 296.24    33 309.87    33 313.05    33 317.67
34 143.34    34 163.18    34 159.56    34 154.29    34 176.9     34 174.89    34 166.56    34 191.47    34 166.93    34 179.03
35 57.075    35 46.687    35 55.465    35 55.262    35 66.724    35 54.365    35 54.765    35 67.914    35 54          35 54.757
36 115.63    36 134.47    36 127.34    36 120.28    36 142.15    36 134.56    36 125.68    36 150.78    36 141.37    36 131.19
37 127.91    37 143.47    37 135.48    37 133.06    37 149.39    37 140.85    37 134.38    37 155.5     37 145.76    37 140.94
38 130.56    38 152.44    38 148.12    38 152.51    38 168.39    38 164.66    38 169.82    38 185.64    38 182.33    38 185.4
39 304830    39 442500    39 492330    39 -453760   39 -38330    39 -307710   39 -114700   39 194710    39 171140    39 -655630
40 2.3585    40 2.3528    40 2.3532    40 2.3537    40 2.3559    40 2.3563    40 2.3568    40 2.399     40 2.3595    40 2.3598
41 37.161    41 42.563    41 43.48     41 44.474    41 50.79     41 51.815    41 53.124    41 60.322    41 61.492    41 63.871
42 38.604    42 34.882    42 34.661    42 35.279    42 39.239    42 39.853    42 46.383    42 45.839    42 45.765    42 46.604
43 48.216    43 44.693    43 45.381    43 46.164    43 56.469    43 51.172    43 51.896    43 56.163    43 56.847    43 57.565
44 27.555    44 39.782    44 28.839    44 25.57     44 39.424    44 19.894    44 25.181    44 41.39     44 19.073    44 24.874
45 365.69    45 414.82    45 422.6     45 431.73    45 488.39    45 468.07    45 497.54    45 546.5     45 554.28    45 563.81
```



SYMBOL	Thermocouple #	Angle(Deg)
A	26	308
B & D	27 & 29	55 & 55
C & E	28 & 30	25 & 25
G & H	38 & 37	86 & 138
I	34	180
J & K	31 & 36	220 & 135
L & M	33 & 32	50 & 295

Circled thermocouples are ½ the depth of the tank back from thermocouples D & E

Number 41 represents pressure in psig.
Number 42 represents time in seconds.

Thermocouple numbers.	Height (cm)	Angle with the vertical (Deg.)	Doubtful or faulty Thermocouple.
34	0	180	-
02	2.54	-	-
08	12.15	-	-
24	15.55	-	-
07	17.56	-	-
18	20.06	-	-
19	22.6	-	-
12	23.7	-	-
05	24.75	-	-
22	25.8	-	-
17	26.8	-	-
23	28.85	-	-
10	29.9	-	-
15	30.9	-	-
16	31.9	-	-
14	32.9	-	-
13	33.95	-	-
11	36.5	-	-
1 & 35	-	42	-
6 & 3	-	86 & 138	-
9 & 25	20.35	-	-
4 & 21	12.20	-	-
30 & 28	-	25 & 25	-
29 & 27	-	55 & 55	-
26	-	308	-
38 & 37	-	86 & 138	-
36 & 31	-	135 & 220	-
32 & 33	-	295 & 50	-
20 & 40	Reference temperature	-	-

Fig. III.C A grid layout of thermocouples for an Explosafe equipped vessel. (Valid for 74, 58 and 23 percent liquid full cases)

RUN NUMBER 7

Q_{IN} = 40 KW/m^2, Set pressure of the PRV=25 psig.

Liquid level = 74%

PRV orifice diameter = 3/8 in.

Explosafe equipped vessel.

```
SCAN # 1      SCAN # 2      SCAN # 3      SCAN # 4      SCAN # 5      SCAN # 6      SCAN # 7      SCAN # 8      SCAN # 9      SCAN # 10
 1 22.873      1 22.883      1 22.963      1 23.959      1 26.229      1 28.074      1 45.062      1 31.767      1 33.[illegible]  1 36.128
 2 22.7        2 22.71       2 23.064      2 23.293      2 23.992      2 24.346      2 25.559      2 26.697      2 27.293      2 26.[illegible]
 3 22.746      3 22.735      3 23.139      3 23.293      3 23.721      3 24.494      3 25.461      3 26.501      3 27.66       3 29.403
 4 22.724      4 22.735      4 22.941      4 23.046      4 23.623      4 24.395      4 25.412      4 26.403      4 27.709      4 23.20[illegible]
 5 22.724      5 22.759      5 22.915      5 23.268      5 25.419      5 26.949      5 29.131      5 30.918      5 33.01       5 34.949
 6 22.7        6 22.685      6 22.915      6 23.095      6 23.746      6 24.863      6 25.706      6 27.554      6 29.296      6 31.105
 7 22.724      7 22.735      7 22.965      7 23.219      7 23.647      7 24.543      7 25.78       7 26.967      7 28.149      7 30.835
 8 22.7        8 22.71       8 22.891      8 23.[illegible]  8 23.549      8 24.274      8 25.313      8 26.403      8 27.665      8 [illegible]
 9 22.7        9 22.71       9 22.94       9 23.317      9 25.321      9 26.802      9 26.18       9 30.407      9 32.261      9 34.25
10 22.799     10 22.685     10 22.915     10 24.5       10 26.597     10 28.44      10 28.276     10 32.276     10 34.242     10 36.464
11 23.021     11 23.031     11 23.039     11 23.761     11 25.296     11 26.704     11 29.106     11 29.823     11 32.114     11 34.686
12 22.724     12 22.735     12 22.915     12 23.219     12 24.657     12 26.508     12 28.326     12 30.363     12 31.856     12 33.792
13 22.973     13 22.685     13 22.915     13 24.156     13 26.229     13 28.098     13 29.638     13 31.743     13 33.88      13 35.912
14 22.873     14 22.583     14 22.891     14 24.16      14 26.332     14 28.172     14 29.96      14 31.913     14 33.904     14 [illegible]
15 22.823     15 22.833     15 22.866     15 24.525     15 26.523     15 28.415     15 30.227     15 32.203     15 34.193     15 36.[illegible]
16 22.673     16 22.858     16 22.915     16 24.402     16 26.474     16 28.343     16 30.154     16 32.131     16 34.121     16 [illegible]
17 22.749     17 22.759     17 23.162     17 23.934     17 26.957     17 27.781     17 29.457     17 31.622     17 33.445     17 35.671
18 22.724     18 22.759     18 22.915     18 23.219     18 23.894     18 25.255     18 26.61      18 26.751     18 30.408     18 33.268
19 22.724     19 22.759     19 22.965     19 23.219     19 24.115     19 26.642     19 27.422     19 29.215     19 31.047     19 33.[illegible]
20 2.764      20 2.765      20 2.7658     20 2.7665     20 2.7674     20 2.7623     20 2.7691     20 2.7701     20 2.7709     20 2.7718
21 22.7       21 22.685     21 22.866     21 23.095     21 23.623     21 24.42      21 25.289     21 26.403     21 27.953     21 [illegible]
22 22.7       22 22.71      22 22.915     22 23.515     22 25.061     22 27.61      22 29.4       22 31.403     22 33.372     22 [illegible]
23 22.724     23 22.735     23 24.991     23 24.746     23 26.621     23 28.465     23 30.276     23 32.227     23 34.[illegible]  23 [illegible]
24 [illegible]  24 22.685   24 22.752     24 23.046     24 23.598     24 24.346     24 25.559     24 [illegible]  24 [illegible]  24 36.416
25 22.875     25 22.685     25 22.641     25 23.219     25 25.025     25 25.336     25 28.253     25 30.013     25 [illegible]  25 [illegible]963
26 22.541     26 [illegible]  26 23.481   26 24.52      26 26.995     26 25.141     26 31.457     26 34.383     26 [illegible]  26 [illegible]835
27 22.541     27 [illegible]  27 23.19    27 24.301     27 [illegible]  27 29.[illegible]  27 30.135  27 33.[illegible]  27 37.148  27 40.[illegible]3
28 22.353     28 22.432     28 24.603     28 24.407     28 29.231     28 32.344     28 36.04      28 37.965     28 44.24      28 40.[illegible]
29 23.079     29 23.181     29 23.752     29 24.843     29 27.188     29 23.526     29 31.918     29 34.747     29 36.006     29 41.507
30 23.174     30 [illegible]  30 25.24    30 27.565     30 31.116     30 34.683     30 38.944     30 43.485     30 48.32      30 [illegible]
31 23.033     31 23.549     31 25.26      31 25.414     31 35.929     31 44.518     31 34.918     31 65.883     31 [illegible]  31 30.556
32 23.194     32 24.226     32 27.984     32 36.36      32 40.534     32 64.293     32 82.141     32 79.741     32 117.17     32 135.05
33 23.031     33 32.637     33 43.235     33 63.803     33 63.673     33 105.81     33 127.36     33 149.5      33 171.19     33 152.52
34 22.626     34 23.588     34 23.5       34 23.702     34 25.064     34 26.153     34 26.142     34 26.73      34 27.915     34 30.56
35 22.903     35 22.93      35 23.055     35 24.456     35 26.571     35 28.448     35 30.304     35 32.33      35 34.41      35 36.64
36 23.852     36 26.236     36 33.115     36 44.141     36 57.373     36 71.774     36 86.518     36 101.42     36 116.2      36 120.75
37 23.23      37 24.42      37 26.245     37 28.027     37 29.115     37 30.623     37 32.167     37 33.75      37 35.241     37 35.969
38 23.019     38 23.455     38 25.163     38 25.364     38 26.339     38 28.197     38 29.923     38 31.651     38 33.759     38 [illegible]
39 -.05601    39 -.05396    39 .00601     39 .01206     39 .03173     39 -.04523    39 -.06513    39 -.00699    39 .01614     39 .048675
40 2.7772     40 2.7779     40 2.7768     40 2.7756     40 2.7805     40 2.7812     40 2.782      40 2.7829     40 2.7838     40 2.7846
41 .02233     41 .01675     41 .00558     41 1.0665     41 2.3787     41 3.7021     41 5.1284     41 6.6782     41 8.3581     41 10.425
42 7.874      42 42.548     42 77.881     42 113.2      42 148.14     42 183.48     42 218.76     42 254.35     42 289.91     42 325.5
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SCAN # 11     SCAN # 12     SCAN # 13     SCAN # 14     SCAN # 15     SCAN # 16     SCAN # 17     SCAN # 18     SCAN # 19     SCAN # 20
 1 35.467      1 40.953      1 43.597      1 46.695      1 45.871      1 51.258      1 52.131      1 52.74       1 45.[illegible]  1 [illegible]
 2 30.479      2 32.143      2 34.91       2 35.421      2 33.801      2 40.953      2 45.433      2 46.001      2 44.[illegible]  2 45.[illegible]
 3 30.553      3 32.458      3 34.26       3 36.359      3 36.24       3 41.625      3 44.967      3 45.553      3 44.[illegible]  3 45.[illegible]
 4 31.017      4 [illegible]  4 34.549     4 36.[illegible]  4 38.264    4 42.371      4 44.324      4 44.773      4 44.[illegible]  4 [illegible]
 5 37.002      5 38.118      5 41.177      5 43.582      5 45.883      5 46.175      5 47.256      5 47.505      5 44.[illegible]  5 48.742
 6 33.313      6 35.21       6 37.142      6 39.366      6 41.673      6 44.076      6 44.361      6 45.223      6 44.515      6 46.661
 7 32.303      7 34.053      7 35.268      7 38.587      7 40.531      7 43.153      7 44.324      7 44.916      7 44.19       7 45.73
 8 38.847      8 32.143      8 34.497      8 36.453      8 38.503      8 42.49       8 44.796      8 45.056      8 44.462      8 45.[illegible]
 9 36.354      9 38.545      9 40.773      9 43.345      9 45.671      9 45.54       9 47.597      9 46.73       9 44.491      9 48.82
10 38.798     10 41.358     10 43.999     10 46.719     10 49.708     10 49.658     10 51.409     10 45.742     10 45.742     10 52.509
11 37.362     11 40.048     11 43.676     11 45.942     11 48.936     11 49.273     11 50.849     11 49.24      11 47.576     11 52.074
12 35.778     12 37.851     12 39.915     12 42.278     12 44.822     12 44.596     12 46.893     12 45.182     12 44.16      12 47.306
13 39.791     13 40.977     13 43.644     13 46.413     13 49.901     13 50.511     13 52.34      13 50.198     13 45.624     13 52.277
14 38.343     14 40.93      14 43.62      14 46.413     14 49.337     14 49.53      14 51.859     14 48.959     14 45.718     14 [illegible]
15 38.726     15 41.31      15 43.551     15 46.746     15 49.755     15 49.904     15 51.479     15 44.773     15 46.118     15 52.679
16 38.678     16 41.262     16 43.975     16 46.789     16 49.778     16 49.928     16 51.582     16 47.633     16 46.189     16 52.[illegible]
17 37.641     17 40.096     17 42.578     17 45.259     17 48.092     17 47.891     17 49.402     17 44.845     17 44.208     17 50.796
18 34.164     18 36.094     18 37.932     18 40.867     18 42.385     18 43.627     18 44.466     18 45.159     18 44.134     18 45.6
19 35.152     19 37.372     19 35.51      19 41.851     19 44.232     19 43.981     19 45.61      19 45.881     19 44.184     19 46.729
20 2.7728     20 2.7728     20 2.7748     20 2.7737     20 2.7769     20 2.7779     20 2.7771     20 2.7793     20 2.7793     20 2.7[illegible]
21 31.466     21 33.135     21 35.266     21 37.438     21 39.161     21 42.371     21 44.466     21 45.317     21 44.208     21 45.753
22 37.506     22 37.746     22 42.27      22 44.505     22 47.412     22 47.443     22 48.629     22 44.704     22 44.231     22 [illegible]
23 36.720     23 41.191     23 43.81      23 46.587     23 49.451     23 49.577     23 51.123     23 44.657     23 46.[illegible]  23 [illegible]
24 31.479     24 33.377     24 35.22      24 37.462     24 39.482     24 42.822     24 44.335     24 45.317     24 44.231     24 45.565
25 35.785     25 37.899     25 40.249     25 42.373     25 44.853     25 44.69      25 46.658     25 44.869     25 44.208     25 49.017
26 44.332     26 44.023     26 51.761     26 55.451     26 59.396     26 37.769     26 38.927     26 57.669     26 50.404     26 56.132
27 44.213     27 47.947     27 51.932     27 56.892     27 60.43      27 63.556     27 66.32      27 63.93      27 64.694     27 65.791
28 54.105     28 53.518     28 65.252     28 71.113     28 77.142     28 82.817     28 88.65      28 68.569     28 88.387     28 52.352
29 45.453     29 49.444     29 55.443     29 58.832     29 67.04      29 67.738     29 71.945     29 72.414     29 73.068     29 75.091
30 59.834     30 64.305     30 65.872     30 75.625     30 81.379     30 84.967     30 88.993     30 82.162     30 81.049     30 [illegible]
31 103.54     31 116.68     31 129.76     31 142.82     31 155.45     31 169.26     31 182.65     31 184.94     31 167.05     31 150.35
32 [illegible]  32 172.71   32 190.53     32 208.21     32 225.24     32 243.43     32 260.72     32 263.75     32 266.4      32 260.[illegible]
33 [illegible]  33 233.94   33 252.63     33 278.97     33 267.88     33 305.44     33 322.45     33 325.38     33 327.92     33 341.62
34 31.563     34 37.266     34 35.384     34 35.585     34 38.405     34 42.667     34 46.668     34 45.379     34 45.896     34 46.094
35 34.[illegible]  35 42.8  35 46.477     35 58.125     35 53.356     35 55.301     35 56.159     35 55.389     35 43.852     35 53.042
36 145.3      36 159.44     36 173.17     36 166.57     36 159.34     36 213.24     36 226.61     36 440.39     36 231        36 242.23
37 37.776     37 39.35      37 41.458     37 44.853     37 46.721     37 49.141     37 51.667     37 45.551     37 47.504     37 52.041
38 37.968     38 40.856     38 42.429     38 45.176     38 47.748     38 48.478     38 49.988     38 45.513     38 46.994     38 51.323
39 .00573     39 -.00390    39 -.05300    39 -.04878    39 -.09833    39 -.07194    39 .00379     39 .01243     39 .01308     39 .066696
40 2.7855     40 2.7663     40 2.7873     40 2.7882     40 2.7892     40 2.7902     40 2.7912     40 2.7915     40 2.7916     40 2.[illegible]
41 14.695     41 15.294     41 18.130     41 21.414     41 25.233     41 25.256     41 27.785     41 17.69      41 21.163     41 29.175
42 361.48     42 398.22     42 434.56     42 471.15     42 507.68     42 540.63     42 589.87     42 597.14     42 603.72     42 640.2
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SCAN # 21     SCAN # 22     SCAN # 23     SCAN # 24     SCAN # 25     SCAN # 26     SCAN # 27     SCAN # 28     SCAN # 29     SCAN # 30

1  51.912     1  46.589     1  53.32      1  53.252     1  49.831     1  54.564     1  55.79      1  54.914     1  53.549     1  51.302
2  46.225     2  45.567     2  46.474     2  46.899     2  46.454     2  48.157     2  48.626     2  47.761     2  48.044     2  46.073
3  46.625     3  45.45      3  46.736     3  47.369     3  46.548     3  48.204     3  48.804     3  47.714     3  48.068     3  46.144
4  45.625     4  45.355     4  46.591     4  46.923     4  46.478     4  47.946     4  48.392     4  47.667     4  47.597     4  46.05
5  45.509     5  45.355     5  50.557     5  50.879     5  46.525     5  51.871     5  51.895     5  47.784     5  47.773     5  46.144
6  46.743     6  45.827     6  47.083     6  47.768     6  46.971     6  48.602     6  49.329     6  46.069     6  48.185     6  46.473
7  46.107     7  45.379     7  46.521     7  47.744     7  46.523     7  48.063     7  46.743     7  47.714     7  47.85      7  46.097
8  46.39      8  45.732     8  47.085     8  47.557     8  46.807     8  48.508     8  49.081     8  47.995     8  48.185     8  46.356
9  48.222     9  45.756     9  50.784     9  49.221     9  46.877     9  52.303     9  50.567     9  48.16      9  48.115     9  46.426
10   46.387   10   46.839   10   53.83    10   47.406   10   47.864   10   55.849   10   49.656   10   48.722   10   47.458   10   46.567
11   50.23    11   49.16    11   57.503   11   52.462   11   50.671   11   64.815   11   58.186   11   53.523   11   53.177   11   51.506
12   46.413   12   45.355   12   50.597   12   48.387   12   46.525   12   51.685   12   49.329   12   47.69    12   47.622   12   46.12
13   50.14    13   46.744   13   53.969   13   51.788   13   47.77    13   56.112   13   53.623   13   49.12    13   46.954   13   46.732
14   48.362   14   46.792   14   53.413   14   50.366   14   47.817   14   54.656   14   51.988   14   48.464   14   46.964   14   46.756
15   45.956   15   47.215   15   53.853   15   49.829   15   48.239   15   55.142   15   52.546   15   48.962   15   47.317   15   47.132
16   46.387   16   47.262   16   53.9     16   50.109   16   48.333   16   55.142   16   52.5     16   48.909   16   47.246   16   47.179
17   46.064   17   45.497   17   53.273   17   47.369   17   48.851   17   54.679   17   48.533   17   48.581   17   47.293   17   46.65
18   46.39    18   45.402   18   48.235   18   47.463   18   46.548   18   46.461   18   48.837   18   47.737   18   47.598   18   46.097
19   46.319   19   45.379   19   49.967   19   47.251   19   46.525   19   51.778   19   48.439   19   47.714   19   47.434   19   46.097
20   2.7946   20   2.7608   20   2.782    20   2.7822   20   2.7824   20   2.7836   20   2.7837   20   2.7839   20   2.7841   20   2.7944
21   46.46    21   45.355   21   46.827   21   47.862   21   46.548   21   48.274   21   49.118   21   47.784   21   47.434   21   46.167
22   45.881   22   45.379   22   51.879   22   47.111   22   46.572   22   53.544   22   48.322   22   47.784   22   47.105   22   46.567
23   45.840   23   47.426   23   53.552   23   47.817   23   48.473   23   54.772   23   48.228   23   49.12    23   46.941   23   46.591
24   46.46    24   45.379   24   46.874   24   47.651   24   46.642   24   48.133   24   48.861   24   47.831   24   47.246   24   [illegible]
25   46.154   25   45.379   25   50.341   25   47.392   25   46.501   25   51.801   25   48.767   25   47.831   25   47.176   25   [illegible]
26   50.021   26   52.404   26   60.215   26   64.618   26   59.815   26   63.845   26   63.778   26   60.025   26   60.553   26   [illegible]
27   64.593   27   63.637   27   69.841   27   67.641   27   66.889   27   72.645   27   71.093   27   69.282   27   67.34    27   65.557
28   92.703   28   73.241   28   99.504   28   90.561   28   99.17    28   105.49   28   105.27   28   105.49   28   104.48   28   104.17
29   75.185   29   75.896   29   79.327   29   79.292   29   80.148   29   84.518   29   84.649   29   85.503   29   85.412   29   85.747
30   85.418   30   64.865   30   95.243   30   90.317   30   91.297   30   100.12   30   95.646   30   96.023   30   93.712   30   95.743
31   200.34   31   202.51   31   213.17   31   215.24   31   217.11   31   227.17   31   229.12   31   230.94   31   233.01   31   234.85
32   283.78   32   286.31   32   300.22   32   302.9    32   305.32   32   317.59   32   319.87   32   321.91   32   324.45   32   326.8
33   344.24   33   346.6    33   359.15   33   361.58   33   363.7    33   375.36   33   377.57   33   379.44   33   381.36   33   382.76
34   46.589   34   45.307   34   47.967   34   47.912   34   47.42    34   49.136   34   49.157   34   48.738   34   47.73    34   [illegible]
35   51.753   35   48.629   35   54.264   35   53.794   35   51.358   35   55.617   35   56.58    35   55.356   35   55.264   35   55.002
36   244.41   36   246.4    36   257.     36   259.86   36   260.95   36   271.82   36   272.98   36   274.74   36   276.59   36   278.2
37   46.782   37   45.056   37   53.684   37   47.893   37   50.072   37   55.253   37   49.119   37   50.918   37   47.587   37   48.433
38   46.664   38   46.252   38   52.622   38   47.874   38   49.125   38   53.617   38   49.1     38   50.139   38   47.492   38   48.044
39   .03665   39 - .06430   39 - .01462   39 - .00262   39 - .00404   39 - .03831   39 - .16483   39 - .07474   39 - .00632   39 - .096758
40   2.7928   40   2.7531   40   2.7941   40   2.7943   40   2.7944   40   2.7955   40   2.7957   40   2.7958   40   2.796    40   2.7962
41   15.018   41   22.559   41   38.482   41   20.476   41   24.877   41   32.665   41   22.823   41   25.351   41   20.035   41   22.175
42   647.48   42   654.86   42   690.51   42   637.87   42   704.46   42   740.37   42   748.14   42   754.72   42   761.39   42   768.5
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SCAN # 31     SCAN # 32     SCAN # 33     SCAN # 34     SCAN # 35

1  53.862     1  58.954     1  54.238     1  53.553     1  54.329
2  48.033     2  47.942     2  46.229     2  47.673     2  48.271
3  47.728     3  47.895     3  46.295     3  47.65      3  48.13
4  47.353     4  46.435     4  46.088     4  47.532     4  48.107
5  50.583     5  49.248     5  46.205     5  47.532     5  48.96
6  47.963     6  46.264     6  46.558     6  48.002     6  48.482
7  [illegible] 7  47.823    7  46.156     7  47.532     7  48.107
8  47.833     8  46.013     8  46.417     8  47.861     8  48.338
9  51.119     9  46.388     9  46.558     9  47.979     9  48.435
10   52.144   10   58.872   10   47.499   10   47.908   10   48.328
11   65.1     11   59.308   11   52.856   11   65.183   11   67.987
12   50.303   12   47.708   12   46.229   12   47.532   12   48.884
13   55.714   13   53.1     13   46.413   13   48.447   13   48.787
14   51.795   14   56.096   14   47.569   14   48.236   14   48.646
15   52.214   15   58.119   15   47.406   15   47.931   15   48.459
16   52.237   16   53.896   16   47.475   16   48.049   16   48.81
17   51.818   17   47.285   17   47.146   17   47.556   17   47.966
18   49.351   18   47.473   18   46.158   18   47.579   18   48.107
19   49.744   19   47.285   19   46.182   19   47.556   19   46.884
20   2.7854   20   2.7857   20   2.7859   20   2.787    20   2.7882
21   47.612   21   47.661   21   46.182   21   47.603   21   48.96
22   51.865   22   47.65    22   47.451   22   47.579   22   47.943
23   51.883   23   46.768   23   47.498   23   47.556   23   46.613
24   47.681   24   47.494   24   46.182   24   47.556   24   48.06
25   49.742   25   47.191   25   46.205   25   47.603   25   48.06
26   63.167   26   64.864   26   62.972   26   62.533   26   70.819
27   74.314   27   73.883   27   70.865   27   73.846   27   75.536
28   103.47   28   100.33   28   107.89   28   109.15   28   109.73
29   84.495   29   88.314   29   88.612   29   89.935   29   91.722
30   101.53   30   97.892   30   98.226   30   99.525   30   100.53
31   244.13   31   246.1    31   247.74   31   257.38   31   260.34
32   338.85   32   340.63   32   342.81   32   316.93   32   311.05
33   385.11   33   384.86   33   384.3    33   369.11   33   356.36
34   48.409   34   47.943   34   46.883   34   46.165   34   48.766
35   57.743   35   59.59    35   60.287   35   59.081   35   60.425
36   285.1    36   285.32   36   286.5    36   265.43   36   281.38
37   53.443   37   47.773   37   48.968   37   48.922   37   49.277
38   51.858   38   47.653   38   48.324   38   48.695   38   49.107
39 - .1325    39 - .10684   39   .00333   39 - .04727   39   .039192
40   2.7971   40   2.7975   40   2.7977   40   2.7988   40   2.8002
41   33.628   41   20.493   41   22.754   41   23.895   41   23.736
42   884.39   42   812.37   42   818.84   42   855.36   42   892.19
```

RUN NUMBER 8

Q_{IN} = 40 KW/m^2, Set pressure of the PRV=25 psig.

Liquid level = 58%

PRV orifice diameter = 3/8 in.

Explosafe equipped vessel.

	SCAN # 1	SCAN # 2	SCAN # 3	SCAN # 4	SCAN # 5	SCAN # 6	SCAN # 7	SCAN # 8	SCAN # 9	SCAN # 10
1	20.646	20.482	20.746	21.082	21.716	22.473	23.772	25.233	26.775	29.575
2	20.671	20.657	20.721	20.834	21.617	21.929	22.711	23.964	24.934	35.506
3	20.597	20.583	20.597	20.785	21.847	21.78	22.612	23.861	25.352	26.652
4	20.597	20.608	20.597	20.785	21.22	21.78	22.761	23.96	25.352	26.864
5	20.553	21.039	21.093	21.305	22.087	23.312	25.421	27.74	30.07	32.352
6	20.597	20.608	20.622	20.859	21.369	22.374	25.2	27.275	28.852	31.063
7	20.597	20.608	20.622	20.81	21.344	22.547	23.674	26.614	28.193	30.062
8	20.597	20.583	20.572	20.76	20.948	21.805	22.736	23.91	28.155	36.374
9	21.043	21.220	21.341	21.553	22.309	23.658	25.868	28.324	30.961	32.5
10	20.919	20.555	21.043	21.231	21.939	22.72	24.166	25.853	27.28	[illegible]
11	20.947	20.558	20.647	20.834	21.135	21.681	22.449	23.393	24.319	35.49
12	20.894	20.755	20.994	21.28	22.26	23.682	25.951	26.375	30.63	33.652
13	20.735	20.856	20.695	21.107	21.641	22.399	23.658	25.166	29.632	28.756
14	20.945	20.856	20.944	21.132	21.691	24.473	23.822	25.313	29.922	[illegible]
15	20.845	20.881	20.919	21.181	21.639	22.646	24.093	25.706	27.464	29.502
16	20.669	20.881	20.944	21.161	21.815	22.946	24.019	25.534	27.24	29.161
17	20.795	20.78	21.068	21.256	21.908	22.967	24.683	26.712	30.701	31.358
18	20.597	20.608	20.795	21.956	23.519	23.11	27.26	29.309	31.043	[illegible]
19	20.845	20.681	20.944	21.454	22.655	24.224	26.599	28.887	31.016	33.311
20	2.4181	2.4192	2.4206	2.422	2.4234	2.4249	2.4265	2.428	2.4294	2.431
21	20.449	20.285	20.249	20.437	20.759	21.557	22.415	23.763	26.309	27.476
22	20.597	20.657	20.746	20.958	21.74	22.819	24.757	26.461	29.316	31.535
23	20.572	20.632	20.671	20.909	21.592	22.497	23.554	25.657	[illegible]	29.54
24	20.374	20.285	20.299	20.407	20.824	21.632	22.933	23.435	[illegible]	[illegible]
25	21.043	21.203	21.415	21.731	22.507	23.756	25.104	28.359	30.608	32.957
26	20.864	20.684	20.945	21.333	22.153	23.355	25.221	27.563	30.531	[illegible]
27	20.722	20.742	20.845	21.197	21.707	22.371	24.899	26.305	[illegible]	[illegible]
28	20.786	20.743	21.233	22.244	23.618	25.967	25.849	31.257	35.56	[illegible]
29	20.703	20.743	21.019	21.682	22.734	24.249	26.341	28.312	31.644	34.759
30	20.742	20.556	21.64	22.844	24.593	26.934	30.879	33.503	38.173	42.949
31	20.6	20.82	21.039	22.399	25.693	31.42	33.714	49.713	60.604	72.585
32	20.697	20.937	21.654	25.031	32.317	43.785	58.674	77.304	97.17	115.16
33	20.458	27.069	34.339	44.915	60.318	79.918	103.1	126.11	146.46	169.49
34	20.425	20.88	20.942	21.567	21.959	22.759	23.035	[illegible]	25.431	[illegible]
35	20.722	20.743	20.864	21.236	21.959	22.739	24.157	45.61	[illegible]	29.305
36	20.936	21.383	24.022	30.217	39.552	51.654	65.937	80.667	55.567	[illegible]
37	20.899	21.111	22.967	24.373	25.848	27.493	29.425	31.447	33.179	35.631
38	20.683	21.17	22.648	24.393	25.464	27.97	29.897	34.918	34.649	36.633
39	-.00057	-.00037	-.00051	-.00057	-.00055	-.00063	-.00058	-.00035	-.00032	-.000441
40	2.4577	2.4578	2.4563	2.4586	2.4592	2.4597	2.4602	2.4605	2.4612	2.4617
41	-1.2693	-1.2588	-1.1558	-.03757	-.31628	.4132	1.6249	2.9818	4.5117	6.3544
42	7.73	33.79	60.494	88.431	118	150.42	185.78	221.11	256.68	292.23

	SCAN # 11	SCAN # 12	SCAN # 13	SCAN # 14	SCAN # 15	SCAN # 16	SCAN # 17	SCAN # 18	SCAN # 19	SCAN # 20
1	30.773	33.462	36.536	40.233	44.587	49.628	56.623	60.253	62.37	62.666
2	33.053	33.341	31.298	34.071	36.611	38.828	41.273	45.55	47.963	43.267
3	33.023	31.813	34.37	36.742	38.958	41.212	44.023	46.374	46.179	46.593
4	33.273	32.131	34.491	36.67	39.885	41.592	44.212	45.833	48.315	46.853
5	34.644	37.072	39.269	41.736	44.256	47.285	50.272	50.592	52.666	48.502
6	34.802	35.553	37.783	40.374	42.836	45.284	40.541	48.886	51.4	49.504
7	32.358	35.878	36.924	39.888	41.768	44.175	46.944	47.889	49.863	48.666
8	33.273	38.894	37.921	35.156	37.953	40.212	42.175	46.115	48.948	46.947
9	35.4	37.743	40.267	42.847	45.554	48.552	51.378	51.128	53.423	48.267
10	32.237	34.573	37.351	40.591	45.954	50.025	51.657	54.219	54.789	54.279
11	26.787	28.868	29.966	31.968	34.381	38.206	44.166	49.564	52.702	53.236
12	35.159	37.192	39.432	41.851	44.469	47.265	49.922	53.755	52.981	45.127
13	30.417	32.664	36.688	40.186	43.688	48.27	52.996	57.774	61.137	56.659
14	30.806	32.76	35.382	38.873	42.386	47.543	51.811	56.438	59.351	56.36
15	31.801	34.889	36.8	40.448	44.114	49.581	51.834	55.537	55.529	54.186
16	31.243	33.341	35.887	39.184	43.897	49.843	52.787	56.945	58.249	55.736
17	34.002	36.4	38.797	41.494	44.469	47.919	50.902	50.873	53.629	51.631
18	34.726	36.832	39.898	41.59	44.867	46.791	44.337	49.636	52.051	48.267
19	33.576	37.44	39.746	42.231	44.894	47.881	50.506	50.942	53.037	48.15
20	2.4325	2.434	2.4356	2.4471	2.4384	2.4398	2.4412	2.4429	2.4445	2.4464
21	30.914	33.196	35.791	38.836	40.127	42.565	45.274	46.186	46.667	48.15
22	34.243	36.736	39.241	42.254	44.823	48.341	51.681	50.825	52.935	47.141
23	32.31	35.829	37.663	41.518	46.731	49.932	51.135	52.129	53.445	52.378
24	31.195	33.265	35.582	37.797	40.174	42.684	45.557	45.456	48.292	47.539
25	35.063	37.158	39.432	41.898	44.516	47.473	50.295	50.848	53.004	47.731
26	38.226	43.264	49.1	56.19	64.163	71.428	75.812	79.58	78.583	79.563
27	37.806	43.321	49.156	54.832	62.419	67.523	69.732	75.339	76.769	76.551
28	44.875	50.857	55.486	61.287	67.683	74.933	84.06	93.114	99.203	90.459
29	38.264	42.122	46.313	50.847	55.855	61.376	67.172	74.725	81.091	81.754
30	48.252	54.864	60.23	66.762	73.714	80.479	87.671	94.847	96.817	99.75
31	87.916	90.546	111.87	124.81	137.63	150.36	162.2	175.19	186.21	199.33
32	133.45	151.79	169.51	187.89	204.63	221.48	237.82	255.55	272.64	275.49
33	173.41	214.59	235.6	255.63	274.02	291.41	308.1	325.65	341.36	343.83
34	28.771	30.72	32.937	34.679	37.888	39.173	41.735	46.84	48.781	49.003
35	34.155	35.823	33.9	46.457	49.683	55.279	63.819	69.763	71.17	71.482
36	124.95	139.43	153.68	167.6	181.11	194.1	206.45	220.89	233.39	235.61
37	36.027	38.898	38.965	41.388	43.721	47.89	50.164	52.142	54.188	48.283
38	36.945	39.015	41.33	43.882	46.171	49.88	51.829	52.81	54.282	48.132
39	-.00049	-.00049	-.00061	-.00055	-.00098	-.00032	-.00047	-.00056	-.00009	-.00074
40	2.4623	2.4629	2.4636	2.4642	2.4647	2.4655	2.466	2.4671	2.4678	2.4673
41	8.1803	10.207	12.847	15.249	16.321	21.894	25.574	25.585	28.343	19.169
42	328.16	364.5	400.62	436.38	473.57	510	546.84	587.1	620.42	655.69

	SCAN # 21	SCAN # 22	SCAN # 23	SCAN # 24	SCAN # 25	SCAN # 26	SCAN # 27	SCAN # 28	SCAN # 29	SCAN # 30
1	61.173	63.515	64.57	62.889	66.764	67.622	65.633	71.818	73.363	69.064
2	46.721	48.451	49.22	47.371	49.146	50.01	48.163	50.542	50.916	48.455
3	46.45	48.39	49.711	47.301	49.87	50.617	47.599	51.809	51.328	48.861
4	46.65	49.668	49.345	47.324	49.45	51.991	48.846	51.638	52.94	48.833
5	47.426	53.627	52.183	48.075	54.592	50.15	48.842	55.627	54.471	49.64
6	47.05	52.582	50.085	47.747	54.291	50.943	48.491	55.234	51.871	49.376
7	46.627	51.139	49.594	47.324	52.202	50.547	48.069	53.544	51.754	48.865
8	46.973	49.294	49.945	47.747	49.824	50.5	48.467	50.916	51.335	49.236
9	49.083	54.206	50.879	48.755	55.17	54.22	49.521	56.204	50.168	50.428
10	51.449	55.779	55.359	52.348	58.374	57.776	54.106	62.135	60.903	56.206
11	50.515	53.603	54.897	51.767	68.143	63.815	54.814	73.258	66.627	55.837
12	47.778	53.719	46.541	48.45	54.661	49.332	49.217	55.696	60.402	[illegible]
13	50.382	60.412	57.781	51.79	65.133	59.088	53.155	70.501	63.31	55.028
14	51.671	60.721	57.525	52.465	63.656	60.626	54.153	64.16	63.219	56.114
15	51.122	56.402	55.244	52.302	59.637	58.121	54.245	62.147	60.662	56.206
16	52.053	59.557	56.973	52.906	63.224	59.957	54.824	66.51	62.781	56.714
17	49.324	53.812	51.764	50.158	54.8	53.873	51.461	56.435	55.504	53.685
18	46.674	53.232	48.916	48.802	54.754	49.776	49.591	55.812	50.776	50.474
19	48.153	53.812	48.916	48.825	54.777	49.589	49.614	55.812	50.426	50.436
20	2.4447	2.4465	2.4461	2.4464	2.4401	2.448	2.4482	2.45	2.45	[illegible]
21	46.344	50.136	49.056	47.163	49.824	49.612	47.905	52.15	[illegible]	48.914
22	48.147	53.719	50.235	48.942	54.707	52.735	51.248	55.858	55.049	[illegible]
23	50.665	54.163	53.228	51.441	56.44	55.007	53.063	59.471	[illegible]	54.866
24	46.731	49.551	48.729	47.371	50.478	49.496	48.022	52.15	50.356	[illegible]
25	48.223	53.766	48.307	48.942	54.731	48.957	49.825	55.766	49.631	58.661
26	81.145	81.36	82.693	84.327	87.025	88.095	89.465	92.434	53.889	95.069
27	72.698	80.039	77.549	74.293	83.932	82.167	76.101	89.312	87.367	82.847
28	76.428	106.05	105.26	105.08	113.56	112.84	112.48	[illegible]	121.41	[illegible]
29	81.94	86.606	87.233	87.475	92.773	93.342	93.713	99.766	100.48	[illegible]
30	101.08	105.62	105.51	107.44	112.46	113.43	114.79	[illegible]	[illegible]	[illegible]
31	192.25	[illegible]	204.72	206.56	218.66	218.75	220.65	[illegible]	[illegible]	[illegible]
32	[illegible]	252.36	259.04	297.45	318.34	312.65	314.79	[illegible]	[illegible]	[illegible]
33	344.19	395.56	348.86	362.93	374.16	376.3	376.5	[illegible]	[illegible]	[illegible]
34	[illegible]	49.548	47.791	48.316	50.73	50.03	49.313	51.634	50.796	49.948
35	71.602	73.399	73.881	74.216	77.061	77.783	77.953	81.94	63.032	82.996
36	237.58	248.74	250.88	252.79	263.27	265.29	267.09	276.49	[illegible]	[illegible]
37	49.914	54.424	48.92	50.731	55.756	49.671	51.5	[illegible]	50.454	[illegible]
38	49.953	55.292	46.712	50.667	56.095	49.711	51.678	[illegible]	50.118	[illegible]
39	-.00060	-.00045	-.00034	-.00047	-.00054	-.00027	-.00037	-.00066	[illegible]	-.000697
40	2.4476	2.4668	2.4465	2.4687	2.47	2.4657	2.4699	2.4712	2.4709	[illegible]
41	22.252	30.462	19.529	23	30.767	20.811	24.318	[illegible]	[illegible]	25.556
42	642.47	679.34	686.62	693.19	729.65	737.12	743.7	720.32	737.6	[illegible]

	SCAN # 31	SCAN # 32	SCAN # 33	SCAN # 34	SCAN # 35
1	68.459	64.681	72.857	74.799	71.223
2	49.193	46.591	48.861	49.585	47.784
3	49.095	46.497	50.123	50.426	47.667
4	49.169	46.45	50.52	52.104	47.591
5	48.214	47.46	54.541	53.369	51.628
6	48.28	47.155	55.074	50.613	49.05
7	48.697	46.497	53.29	50.477	47.784
8	49.333	46.596	49.633	50.566	48.136
9	[illegible]	47.93	55.143	54.332	51.252
10	55.171	52.111	64.494	62.855	56.669
11	56.605	52.46	76.069	69.602	55.931
12	48.045	47.625	54.634	49.329	49.05
13	54.552	50.49	74.966	65.967	55.294
14	55.379	51.482	71.558	65.263	56.3
15	[illegible]	52.111	66.376	63.014	56.778
16	[illegible]	52.111	69.198	64.033	56.784
17	[illegible]	51.156	57.45	56.528	54.834
18	48.35	47.977	54.75	49.256	49.481
19	47.857	48.033	54.727	48.953	47.424
20	2.4506	2.4548	2.4526	2.4525	2.4528
21	48.115	46.379	51.593	49.421	47.62
22	52.342	49.836	58.975	54.865	53.176
23	[illegible]	51.469	61.51	58.484	55.353
24	47.704	46.426	52.709	49.187	47.761
25	[illegible]	48.234	54.79	48.86	49.752
26	94.649	74.229	90.493	108.17	100.87
27	[illegible]	77.19	93.847	91.797	96.436
28	120.38	119.5	131.92	131.1	130.29
29	100.58	100.53	106.37	107.77	108.12
30	123.03	123.21	128.65	140.56	131.36
31	236.4	238.83	246.58	248.81	249.48
32	332.71	334.66	345.64	347.74	349.64
33	395.99	397.33	408.14	409.93	411.6
34	48.49	47.74	49.603	49.733	48.751
35	62.569	81.575	65.753	87.101	86.593
36	302.52	284.23	393.69	295.48	297.09
37	48.143	49.767	55.762	49.316	51.155
38	47.542	51.451	70.767	46.691	55.328
39	-.00038	-.00058	-.00066	-.00065	-.000426
40	2.471	2.4718	2.4725	2.4722	2.4725
41	13.024	22.313	31.169	20.548	24.235
42	801.45	808.82	645.28	852.55	859.13

RUN NUMBER 9

Q_{IN} = 40 KW/m^2, Set pressure of the PRV=25 psig.

Liquid level = 23%.

PRV orifice diameter = 3/8 in.

Explosafe equipped vessel.

	SCAN # 1		SCAN # 2		SCAN # 3		SCAN # 4		SCAN # 5		SCAN # 6		SCAN # 7		SCAN # 8		SCAN # 9		SCAN # 10
1	31.059	1	31.059	1	31.189	1	31.279	1	31.74	1	32.756	1	34.809	1	37.333	1	39.749	1	43.1
2	27.796	2	27.818	2	28.431	2	28.919	2	30.234	2	32.086	2	33.941	2	36.397	2	38.842	2	41.297
3	29.478	3	29.551	3	29.894	3	30.745	3	32.176	3	34.037	3	35.676	3	37.003	3	40.365	3	42.982
4	29.888	4	29.137	4	29.309	4	29.796	4	31.109	4	32.756	4	34.809	4	37.357	4	39.749	4	42.223
5	30.324	5	30.597	5	30.745	5	31.061	5	31.691	5	32.95	5	34.858	5	37.357	5	39.749	5	42.247
6	30.5	6	30.573	6	30.818	6	31.23	6	31.902	6	33.191	6	35.074	6	37.62	6	40.035	6	42.579
7	29.643	7	29.892	7	30.964	7	30.429	7	31.303	7	32.732	7	34.809	7	37.333	7	39.749	7	42.323
8	29.137	8	29.185	8	29.487	8	29.943	8	31.279	8	32.95	8	35.002	8	37.572	8	40.012	8	42.555
9	30.791	9	30.609	9	31.036	9	31.473	9	32.225	9	33.312	9	35.098	9	37.62	9	40.059	9	42.603
10	30.906	10	30.906	10	31.085	10	31.4	10	31.902	10	33.071	10	35.05	10	37.596	10	40.083	10	43.124
11	30.013	11	29.989	11	30.84	11	30.064	11	31.012	11	32.684	11	34.713	11	37.261	11	39.678	11	42.176
12	30.33	12	30.427	12	30.599	12	30.939	12	31.594	12	32.653	12	34.858	12	37.357	12	39.749	12	42.271
13	30.64	13	30.816	13	30.691	13	31.158	13	31.613	13	33.119	13	35.147	13	37.644	13	40.417	13	43.069
14	30.816	14	30.816	14	30.831	14	31.206	14	31.037	14	33.022	14	34.906	14	37.404	14	39.621	14	43.1
15	30.867	15	30.689	15	31.012	15	31.329	15	31.085	15	33.022	15	35.05	15	37.62	15	40.107	15	43.219
16	30.777	16	30.689	16	31.012	16	31.352	16	31.934	16	33.095	16	35.074	16	37.62	16	40.107	16	43.55
17	30.694	17	30.694	17	30.866	17	31.206	17	31.728	17	33.022	17	34.954	17	37.404	17	39.821	17	42.343
18	30.839	18	30.111	18	30.259	18	30.623	18	31.449	18	32.877	18	34.906	18	37.36	18	39.797	18	42.315
19	30.232	19	30.305	19	30.453	19	30.842	19	31.594	19	32.926	19	34.53	19	37.404	19	39.821	19	44.316
20	2.5957	20	2.5957	20	2.5959	20	2.5959	20	2.5959	20	2.5958	20	2.5959	20	2.5955	20	2.5961	20	2.5961
21	29.746	21	29.843	21	30.964	21	30.453	21	31.352	21	32.829	21	34.906	21	37.38	21	39.797	21	42.294
22	30.548	22	30.573	22	30.745	22	31.061	22	31.691	22	32.95	22	34.906	22	37.38	22	39.621	22	42.294
23	30.767	23	30.767	23	30.891	23	31.133	23	31.647	23	32.877	23	34.906	23	37.404	23	39.821	23	42.484
24	29.453	24	29.526	24	29.723	24	30.113	24	31.158	24	32.78	24	34.982	24	37.404	24	39.797	24	42.318
25	30.946	25	31.003	25	31.279	25	31.643	25	32.297	25	33.288	25	35.002	25	37.404	25	39.797	25	42.318
26	31.543	26	31.619	26	31.920	26	32.599	26	33.826	26	35.743	26	38.63	26	42.71	26	47.823	26	53.[illegible]
27	31.274	27	31.274	27	31.429	27	31.908	27	32.687	27	34.46	27	38.681	27	37.737	27	43.682	27	46.141
28	31.304	28	31.735	28	32.715	28	34.362	28	36.641	28	[illegible]	28	42.681	28	46.985	28	51.845	28	56.947
29	31.254	29	31.37	29	31.547	29	33.078	29	34.727	29	36.872	29	39.451	29	42.481	29	45.772	29	49.793
30	31.466	30	31.946	30	33.329	30	35.338	30	38.132	30	41.453	30	45.447	30	50.263	30	55.673	30	61.911
31	30.024	31	30.101	31	31.025	31	34.44	31	40.461	31	40.596	31	56.263	31	68.971	31	80.114	31	91.528
32	27.944	32	26.079	32	30.682	32	32.61	32	50.999	32	66.277	32	64.06	32	104.38	32	123.45	32	142.12
33	30.043	33	27.903	33	31.387	33	78.782	33	93.254	33	116.47	33	130.35	33	140.33	33	181.18	33	201.79
34	27.732	34	26.214	34	28.543	34	30.043	34	31.466	34	33.31	34	35.207	34	37.713	34	40.403	34	43.378
35	31.456	35	31.447	35	31.544	35	31.631	35	32.445	35	33.54	35	35.322	35	38	35	41.683	35	46.479
36	26.729	36	27.849	36	33.732	36	44.135	36	57.076	36	71.287	36	85.834	36	100.35	36	115.32	36	129.[illegible]
37	29.119	37	30.843	37	32.696	37	36.431	37	40.976	37	46.074	37	51.379	37	56.776	37	62.155	37	67.814
38	30.774	38	31.406	38	33.617	38	36.852	38	40.899	38	45.713	38	51.265	38	57.36	38	63.919	38	78.941
39	.84041	39	.12812	39	.07712	39	.05528	39	.0923	39	-.03950	39	-.06595	39	-.17787	39	-.116	39	-.013974
40	2.6131	40	2.6131	40	2.6132	40	2.6131	40	2.6131	40	2.6132	40	2.6132	40	2.6132	40	2.6134	40	2.6134
41	2.563	41	2.6858	41	3.4117	41	4.3945	41	5.8239	41	7.4488	41	9.4534	41	11.916	41	14.289	41	16.502
42	7.87	42	42.395	42	77.85	42	112.88	42	140.39	42	183.84	42	219.19	42	254.75	42	290.44	42	326.16

	SCAN # 11		SCAN # 12		SCAN # 13		SCAN # 14		SCAN # 15		SCAN # 16		SCAN # 17		SCAN # 18		SCAN # 19		SCAN # 20
1	47.441	1	51.93	1	56.862	1	61.864	1	66.526	1	67.656	1	64.168	1	70.43	1	71.954	1	67.975
2	44.143	2	47.33	2	50.415	2	52.372	2	54.189	2	51.933	2	43.933	2	48.962	2	49.351	2	41.37
3	45.889	3	48.989	3	52.418	3	55.062	3	56.728	3	57.603	3	56.221	3	56.892	3	52.367	3	56.892
4	44.393	4	47.958	4	51.184	4	53.116	4	53.281	4	53.629	4	50.769	4	51.066	4	52.585	4	49.651
5	44.993	5	47.501	5	51.65	5	54.577	5	56.751	5	57.557	5	53.329	5	58.71	5	57.671	5	54.382
6	45.37	6	48.28	6	51.65	6	53.696	6	54.963	6	55.649	6	51.632	6	55.654	6	56.89	6	[illegible]
7	45.016	7	47.981	7	51.161	7	53.133	7	53.258	7	50.512	7	44.944	7	51.191	7	51.374	7	50.001
8	45.347	8	48.356	8	51.004	8	53.603	8	53.639	8	51.211	8	44.990	8	51.364	8	49.462	8	44.633
9	45.394	9	46.45	9	52.139	9	54.993	9	57.626	9	54.006	9	54.349	9	59.421	9	60.176	9	55.50
10	46.394	10	50.858	10	55.038	10	58.842	10	62.163	10	61.478	10	54.117	10	65.356	10	64.577	10	55.554
11	44.946	11	47.684	11	51.891	11	53.093	11	64.326	11	63.872	11	51.063	11	67.162	11	62.285	11	51.09
12	45.916	12	48.885	12	51.441	12	54.867	12	55.885	12	56.197	12	52.539	12	57.632	12	58.818	12	53.794
13	47.605	13	51.946	13	56.609	13	61.818	13	64.735	13	61.204	13	52.627	13	68.81	13	64.305	13	52.68
14	47.441	14	51.86	14	56.517	14	60.927	14	64.758	14	61.844	14	53.445	14	67.75	14	64.373	14	54.163
15	47.888	15	51.371	15	55.663	15	60.195	15	64.089	15	61.321	15	54.326	15	66.663	15	63.964	15	55.276
16	47.746	16	52.116	16	56.862	16	62.384	16	65.597	16	62.095	16	54.193	16	66.346	16	64.305	16	54.637
17	45.134	17	48.[illegible]	17	51.953	17	55.062	17	57.557	17	57.189	17	52.775	17	60.017	17	57.304	17	54.351
18	45.027	18	48.052	18	51.417	18	53.905	18	55.25	18	55.366	18	52.097	18	56.293	18	56.152	18	55.634
19	45.087	19	48.052	19	51.63	19	54.345	19	56.128	19	56.013	19	52.562	19	57.36	19	57.121	19	53.261
20	2.5962	20	2.5963	20	2.5963	20	2.5964	20	2.5967	20	2.5967	20	2.5968	20	2.597	20	2.5968	20	2.597
21	45.863	21	48.828	21	51.254	21	53.232	21	53.813	21	53.583	21	50.806	21	53.586	21	53.282	21	49.931
22	45.027	22	48.875	22	51.836	22	54.53	22	57.235	22	56.474	22	52.818	22	59.352	22	58.179	22	53.[illegible]
23	45.303	23	49.527	23	53.579	23	56.748	23	59.028	23	56.935	23	52.934	23	62.645	23	59.603	23	54.513
24	45.087	24	49.075	24	51.301	24	53.255	24	53.792	24	53.467	24	50.749	24	53.864	24	53.282	24	50.671
25	45.111	25	48.052	25	51.278	25	53.371	25	56.662	25	56.477	25	53.653	25	59.673	25	53.[illegible]	25	55.369
26	54.905	26	64.743	26	70.96	26	77.475	26	64.05	26	85.365	26	86.054	26	71.361	26	53.004	26	94.601
27	54.139	27	64.352	27	66.617	27	73.059	27	79.299	27	78.873	27	76.196	27	85.183	27	64.65	27	92.347
28	63.056	28	69.603	28	74.638	28	84.233	28	92.392	28	93.132	28	93.724	28	101.68	28	102.53	28	103.17
29	54.553	29	55.958	29	65.718	29	72.335	29	78.946	29	79.95	29	80.509	29	85.646	29	86.739	29	87.442
30	68.337	30	74.85	30	61.637	30	88.714	30	96.358	30	97.317	30	90.327	30	105.26	30	106.44	30	107.5
31	104.47	31	116.87	31	129.17	31	143.12	31	157.89	31	160.35	31	162.42	31	173.49	31	[illegible]	31	178.35
32	160.32	32	178.36	32	137.44	32	216.74	32	236.38	32	239.54	32	242.35	32	257.55	32	260.47	32	263.07
33	222.66	33	243.19	33	263.24	33	284.97	33	307.6	33	311.17	33	314.53	33	332.39	33	335.6	33	339.01
34	45.335	34	48.2	34	51.159	34	57.271	34	53.[illegible]	34	49.095	34	44.828	34	50.473	34	46.101	34	45.527
35	51.949	35	57.682	35	63.374	35	63.553	35	75.467	35	76.604	35	76.941	35	81.456	35	62.665	35	87.441
36	144.35	36	159.57	36	172.46	36	107.68	36	183.5	36	206.01	36	208.28	36	220.6	36	222.97	36	185.13
37	72.968	37	76.441	37	63.937	37	88.954	37	93.61	37	93.574	37	94.314	37	98.958	37	99.786	37	100.39
38	76.107	38	85.64	38	93.442	38	102.15	38	111.77	38	113.16	38	114.56	38	123.31	38	124.7	38	125.33
39	-.11312	39	-.05644	39	-.03058	39	-.03265	39	-.000811	39	.01733	39	-.07535	39	-.00871	39	-.14307	39	.0079
40	2.6134	40	2.6134	40	2.6135	40	2.6135	40	2.6137	40	2.6138	40	2.614	40	2.614	40	2.614	40	2.614
41	10.118	41	23.794	41	27.997	41	34.761	41	30.979	41	16.339	41	30.956	41	28.098	41	13.959	41	18.628
42	362.47	42	336.67	42	435.14	42	476.25	42	520.5	42	327.87	42	534.46	42	571.11	42	378.36	42	585.63

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SCAN # 21    SCAN # 22    SCAN # 23    SCAN # 24    SCAN # 25    SCAN # 26    SCAN # 27    SCAN # 28    SCAN # 29    SCAN # 30

 1 75.797     1 77.553     1 73.878     1 81.646     1 83.647     1 79.4       1 69.053     1 91.329     1 84.792     1 57.202
 2 47.166     2 47.661     2 39.737     2 46.418     2 47.829     2 38.737     2 [illegible] 2 47.315    2 38.477     2 46.944
 3 [illegible] 3 59.445    3 57.482     3 59.746     3 61.[illegible] 3 59.837  3 [illegible] 3 65.[illegible] 3 61.949 3 [illegible]
 4 51.379     4 62.303     4 48.929     4 51.847     4 52.863     4 [illegible] 4 53.593     4 54.851     4 50.[illegible] 4 [illegible]
 5 [illegible] 5 [illegible] 5 56.734   5 66.284     5 [illegible] 5 59.085    5 [illegible] 5 72.321     5 62.858     5 [illegible]
 6 [illegible] 6 [illegible] 6 52.428   6 60.364     6 61.713     6 54.144     6 64.018     6 65.404     6 56.347     6 62.[illegible]
 7 73.033     7 56.363     7 [illegible] 7 57.587    7 58.254     7 53.127     7 60.46      7 61.511     7 55.239     7 [illegible]
 8 50.298     8 64.65      8 47.085     8 51.218     8 52.88      8 48.275     8 [illegible] 8 54.682     8 58.033     8 [illegible]
 9 62.736     9 63.648     9 56.544     9 65.672     9 66.668     9 59.954     9 70.55      9 71.537     9 63.177     9 [illegible]
10 69.053    10 66.728    10 57.563    10 74.731    10 73.57     10 60.572    10 80.908    10 79.553    10 63.769    10 87.899
11 70.34     11 71.351    11 52.892    11 75.711    11 76.956    11 54.75     11 83.277    11 84.112    11 58.052    11 [illegible]
12 61.116    12 61.926    12 55.88     12 64.742    12 64.969    12 55.44     12 69.245    12 65.[illegible] 12 61.444 12 [illegible]
13 73.679    13 60.679    13 53.658    13 79.173    13 73.637    13 55.906    13 86.782    13 79.906    13 58.038    13 [illegible]
14 [illegible] 14 [illegible] 14 55.857 14 78.132    14 73.401    14 [illegible] 14 85.494   14 [illegible] 14 [illegible] 14 [illegible]
15 70.[illegible] 15 66.644 15 [illegible] 15 76.823  15 [illegible] 15 [illegible] 15 [illegible] 15 78.[illegible] 15 63.[illegible] 15 [illegible]
16 77.053    16 66.319    16 56.987    16 76.467    16 73.658    16 56.862    16 85.363    16 76.645    16 [illegible] 16 [illegible]
17 [illegible] 17 64.351  17 56.18     17 68.137    17 66.[illegible] 17 59.014 17 [illegible] 17 71.717    17 [illegible] 17 [illegible]
18 58.549    18 58.619    18 53.89     18 61.325    18 61.874    18 55.431    18 65.886    18 64.745    18 [illegible] 18 [illegible]
19 66.567    19 60.247    19 [illegible] 19 64.219   19 63.582    19 57.52     19 68.[illegible] 19 67.847 19 60.[illegible] 19 74.803
20 [illegible] 20 [illegible] 20 2.5973 20 2.5974    20 2.5974    20 2.5976    20 2.5978    20 2.5978    20 [illegible] 20 2.5983
21 [illegible] 21 [illegible] 21 [illegible] 21 54.841 21 54.331   21 50.124    21 57.314    21 56.9      21 [illegible] 21 [illegible]
22 [illegible] 22 61.459  22 55.926    22 [illegible] 22 65.037   22 [illegible] 22 [illegible] 22 [illegible] 22 61.[illegible] 22 [illegible]
23 [illegible] 23 62.714  23 [illegible] 23 71.152   23 66.419    23 59.61     23 76.583    23 [illegible] 23 63.109   23 [illegible]
24 [illegible] 24 [illegible] 24 50.728 24 58.042    24 55.28     24 51.[illegible] 24 58.878 24 58.[illegible] 24 [illegible] 24 [illegible]
25 [illegible] 25 61.[illegible] 25 56.649 25 66.467  25 [illegible] 25 59.[illegible] 25 [illegible] 25 69.493 25 63.019  25 [illegible]
26 120.1     26 [illegible] 26 102.88  26 [illegible] 26 111.[illegible] 26 [illegible] 26 119.37 26 121.6     26 [illegible] 26 [illegible]
27 92.34     27 92.416    27 67.139    27 100.62    27 100.[illegible] 27 96.309 27 [illegible] 27 110.41   27 [illegible] 27 [illegible]
28 112.49    28 [illegible] 28 113.44  28 123.08    28 123.77    28 124.[illegible] 28 [illegible] 28 135.99 28 [illegible] 28 [illegible]
29 [illegible] 29 94.427  29 [illegible] 29 101.39   29 102.88    29 103.[illegible] 29 [illegible] 29 [illegible] 29 [illegible] 29 [illegible]
30 [illegible] 30 116.06  30 117.19    30 124.99    30 126.36    30 [illegible] 30 [illegible] 30 [illegible] 30 [illegible] 30 [illegible]
31 [illegible] 31 131.57  31 134.[illegible] 31 205.63 31 206.[illegible] 31 [illegible] 31 [illegible] 31 [illegible] 31 [illegible] 31 [illegible]
32 [illegible] 32 [illegible] 32 232.[illegible] 32 [illegible] 32 290.77 32 301.[illegible] 32 314.[illegible] 32 [illegible] 32 [illegible] 32 [illegible]
33 [illegible] 33 [illegible] 33 [illegible] 33 [illegible] 33 330.4 33 323.[illegible] 33 [illegible] 33 400.[illegible] 33 [illegible] 33 [illegible]
34 [illegible] 34 [illegible] 34 41.861 34 [illegible] 34 43.463    34 [illegible] 34 [illegible] 34 43.[illegible] 34 39.656 34 [illegible]
35 [illegible] 35 90.495  35 91.103    35 97.81     35 76.741    35 [illegible] 35 106.[illegible] 35 107.[illegible] 35 108.44 35 [illegible]
36 236.3     36 235.64    36 241.83    36 252.31    36 254.42    36 [illegible] 36 267.76    36 264.8     36 [illegible] 36 [illegible]
37 105.61    37 106.63    37 107.45    37 113.3     37 114.65    37 115.[illegible] 37 122.38 37 124.05    37 124.88    37 [illegible]
38 135.11    38 136.48    38 137.77    38 147.27    38 140.54    38 145.[illegible] 38 159.88 38 161.07    38 162.19    38 [illegible]
39 .05330    39 .01452    39 -.03538   39 .00452    39 -.62401   39 -.07545   39 -.00407   39 .02240    39 -.00215   39 [illegible]
40 2.6142    40 2.6142    40 2.614     40 2.6144    40 2.6144    40 2.6144    40 2.6147    40 2.6146    40 2.6146    40 [illegible]
41 26.423    41 14.3      41 17.842    41 25.613    41 13.256    41 16.176    41 25.903    41 12.994    41 16.007    41 26.608
42 621.87    42 629.14    42 635.72    42 672.47    42 680.75    42 667.33    42 727.75    42 735.02    42 741.6     42 783.[illegible]
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SCAN # 31    SCAN # 32    SCAN # 33    SCAN # 34    SCAN # 35

 1 99.71      1 [illegible] 1 104.[illegible] 1 105.79  1 100.79
 2 47.837     2 [illegible] 2 [illegible] 2 46.617    2 38.393
 3 62.393     3 [illegible] 3 72.[illegible] 3 74.612  3 59.91
 4 [illegible] 4 [illegible] 4 [illegible] 4 61.884  4 [illegible]
 5 [illegible] 5 [illegible] 5 82.[illegible] 5 83.574 5 70.921
 6 [illegible] 6 [illegible] 6 [illegible] 6 74.656  6 [illegible]
 7 [illegible] 7 [illegible] 7 67.948   7 68.963     7 60.701
 8 [illegible] 8 [illegible] 8 [illegible] 8 60.745  8 [illegible]
 9 76.51      9 66.76      9 81.108     9 62.277     9 [illegible]
10 89.357    10 67.401    10 95.681    10 93.266    10 72.669
11 90.858    11 61.517    11 90.[illegible] 11 98.26 11 65.121
12 74.426    12 64.41     12 73.673    12 79.983    12 68.852
13 86.656    13 68.946    13 103.45    13 93.849    13 65.778
14 [illegible] 14 64.637  14 101.57    14 93.612    14 69.665
15 84.643    15 [illegible] 15 97.486  15 91.535    15 [illegible]
16 85.[illegible] 16 66.157 16 101.4   16 92.25     16 [illegible]
17 77.[illegible] 17 [illegible] 17 85.332 17 [illegible] 17 70.494
18 68.687    18 68.397    18 74.059    18 73.473    18 64.212
19 72.506    19 [illegible] 19 79.854  19 77.748    19 67.114
20 2.5964    20 2.5984    20 2.5945    20 2.599     20 2.5991
21 59.347    21 54.318    21 64.256    21 83.506    21 57.557
22 74.907    22 64.[illegible] 22 84.143 22 88.371  22 69.91
23 76.321    23 [illegible] 23 98.162  23 82.[illegible] 23 72.244
24 80.[illegible] 24 [illegible] 24 65.[illegible] 24 84.507 24 [illegible]
25 74.562    25 [illegible] 25 82.973  25 80.248    25 [illegible]
26 132.37    26 [illegible] 26 142.[illegible] 26 144.9 26 146.[illegible]
27 [illegible] 27 [illegible] 27 132.27 27 133.31   27 126.79
28 [illegible] 28 145.[illegible] 28 [illegible] 28 162.22 28 162.83
29 121.6     29 [illegible] 29 130.37  29 131.[illegible] 29 132.85
30 148.12    30 148.92    30 [illegible] 30 160.88  30 160.[illegible]
31 240.48    31 [illegible] 31 253.35  31 255.22    31 256.29
32 [illegible] 32 336.25  32 344.[illegible] 32 350.[illegible] 32 [illegible]
33 440.22    33 [illegible] 33 436.47  33 438.51    33 440.[illegible]
34 43.483    34 [illegible] 34 48.047  34 43.493    34 39.[illegible]
35 110.[illegible] 35 [illegible] 35 126.68 35 128.87 35 129.16
36 [illegible] 36 [illegible] 36 297.[illegible] 36 290.98 36 300.57
37 [illegible] 37 [illegible] 37 142.5 37 144.85    37 144.77
38 173.83    38 175.88    38 186.41    38 187.68    38 166.96
39 .05773    39 .03964    39 .08257    39 .11664    39 -.015727
40 2.6147    40 2.615     40 2.6152    40 2.6155    40 2.6155
41 12.848    41 15.813    41 27.863    41 13.488    41 16.517
42 790.64    42 797.21    42 840.06    42 847.32    42 853.9
```

III.1 Heat Transfer in the UNB Vessel Using An Alternate Method

An energy balance on the heater wire based on Fig. 4.5 is given as follows:

$$Q_{IN} = Q_{RLA} + Q_{CONDG} + Q_{RS}$$

$$= \sigma(T_{WIRE}^4 - T_{LA}^4) + \frac{kg(T_{WIRE} - Tg)}{drg} + \sigma(T_{WIRE}^4 - T_W^4) \qquad (A)$$

On the right hand side of equation (A), the wire and the gas temperatures are unknown. Therefore the gas temperature in the gap is assumed as follows:

$$Tg = \frac{T_{LA} - T_W}{2} \qquad (B)$$

Substituting eqn. (B) in the eqn. (A), we have

$$Q_{IN} = \sigma(T_{WIRE}^4 - T_{LA}^4) + \frac{kg}{2drg}(2T_{WIRE} - T_{LA} - T_W) + \sigma(T_{WIRE}^4 - T_W^4$$

$$= \sigma T_{WIRE}^4 - \sigma T_{LA}^4 + \frac{kg \cdot T_{WIRE}}{drg} - \frac{kg}{2drg}(T_{LA} + T_W) + \sigma T_{WIRE}^4 - \sigma T_W^4$$

$$0 = 2\sigma T_{WIRE}^4 + \frac{kg \cdot T_{WIRE}}{drg} - (\sigma(T_{LA}^4 + T_W^4) + \frac{kg}{2drg}(T_{LA} + T_W) + Q_{IN}) \qquad (C)$$

where

kg = thermal conductivity of gas,

σ = Stefan Boltzman constant (5.669E-08 W/m^{2}k^4), and

drg = distance between the coil centre and the outer surface of the inner vessel (0.0063 m).

In the case of argon gas, kg = 0.00635 W/m-°C. Substituting the values of constants, equation (C) becomes:

$$0 = 1.1338E\text{-}07\ T_{WIRE}^4 + 0.99\ T_{WIRE} - (5.669E\text{-}09(T_{LA}^4 + T_W^4) + 0.496\ (T_{LA} + T_W) + Q_{IN}) \qquad (D)$$

If the gas is air, then kg = 0.466 W/m-°C. Substituting values of constants in eqn. (C), we have

$$0 = 1.1338E\text{-}07\ T_{WIRE}^4 - 7.337\ T_{WIRE} - (5.669E\text{-}08(T_{LA}^4 - T_W^4) - 3.669\ (T_{LA} - T_W) - Q_{IN}) \qquad (E)$$

From all experimental runs, the temperatures of the lava and the vapour space wall at all time levels are known. The only unknown parameter on the right hand of equation (D) and (E) is the heater wire temperature. Therefore, the bisection and secant method for finding the roots of a non-linear equation is used to find these wire temperatures for various time steps.

III.2 Heat Transfer in the Vapour Space of An Unprotected Vessel

An energy balance in the vapour space of the unprotected vessel is (Fig. 4.3):

$$Q_{IN} = Q_{RE} + Q_{RI} + Q_{ST} - Q_{COND} - Q_{CONV} \qquad (F)$$

In order to calculate the heat radiated Q_{RE} from the external surface to surroundings is given by Holman [11]

$$Q_{RE} = \sigma \varepsilon_s T_W^4 \tag{G}$$

From assumption 1 in section (4.1), T_W (internal) = T_W (external). The heat energy radiated from the vapour space wall to the liquid surface is evaluated by an equation [11]:

$$Q_{RI} = \frac{\sigma(T_W^4 - T_L^4)}{\frac{1-\varepsilon_W}{\varepsilon_W} - \frac{1}{F_{W-L}} - \frac{1-\varepsilon_L}{\varepsilon_L}\left(\frac{A_W}{A_L}\right)} \tag{H}$$

In this case, the emissivity of an inner wall ε_W is assumed to be constant as 0.65 due to corrosion and external heating effects, whereas the ε_L is taken as 0.8 [11]. The view factor F_{W-L} is evaluated using the reciprocity relation [11]:

$$A_W F_{W-L} = A_L F_{L-W} \tag{I}$$

The propane vapour is optically transparent because 86% of the total energy radiated by the vapour space wall at 850°C will reach the liquid surface unattenuated within the wavelength intervals of $2.6\ \mu m < \lambda < 3.3\ \mu m$, $3.6\ \mu m < \lambda < 6.5\ \mu m$ and $7.7\ \mu m < \lambda < 2.2\ \mu m$ [13]. Therefore, the liquid surface sees only the vapour space wall and the view factor F_{L-W} becomes equal to 1. A_W and A_L are the surface areas of wall and liquid respectively and the view factor F_{W-L} is calculated as follows:

$$F_{W-L} = \frac{A_L}{A_W} \tag{J}$$

The view factor or shape factor F_{W-L} is dependent on the surface areas of the wall and the liquid which are in fact dependent on the liquid levels. For different liquid levels, these areas as well as view factors are evaluated and averaged on time.

The heat stored Q_{ST} in the vapour space wall at any time level is approximated as:

$$Q_{ST} = \rho_s * C_{p_s} * t_s * \frac{(T_W^{(n-1)} - T_W^{(1)})}{(\tau^{(n-1)} - \tau^{(1)})} \tag{K}$$

Further, the convective heat transfer in the vapour space is written as under:

$$Q_{CONV} = h(T_W^{(n)} - T_V^{(n)}) \tag{L}$$

The heat conducted circumferentially at the interface is negligible based on assumption (7) in section (4.1) and the complete energy balance in an equation form is written as follows:

$$Q_{IN} = Q_{RE} + Q_{RI} + Q_{ST} + Q_{CONV}$$

$$Q_{IN} = \sigma\epsilon_s T_W^4 + \frac{\sigma(T_W^4 - T_L^4)}{\frac{1-\epsilon_W}{\epsilon_W} + \frac{1}{F_{W-L}} + \frac{1-\epsilon_L}{\epsilon_L}(\frac{A_W}{A_L})} + \rho_s C_{p_s} t_s \frac{(T_W^{(n+1)} - T_W^{(1)})}{(\tau^{(n+1)} - \tau^{(1)})}$$

$$+ h(T_W^{(n)} - T_V^{(n)}) \tag{M}$$

III.3 Sample Calculations

III.3.1 Conduction Heat Transfer in the Vapour Space

Note: All the data in the following calculations have been taken from Figs. 3.1 and 3.3. Only the data not presented in these figures is taken from the run number 1 (Appendix III).

For UNB vessel (76% full; $Q = 65\ \mathrm{kW/m^2}$ and
PRV orifice = 1/4" ϕ)

The conduction heat transfer in the vapour space is given by

$$Q_C = K_V \frac{dT}{dr}$$

$$= K_V \frac{(T_W - T_V)}{dr}$$

(i) $T_W = 62^\circ C$ at 180 seconds

$T_V = 31.5^\circ C$ at 180 seconds

$T_m = \frac{(62 - 31.5)}{2} = 46.75^\circ C$ (film temperature)

$K_V = 0.007 * \mathrm{Exp}(T_m * 0.005)$

$= 0.007 * \mathrm{Exp}(46.75 * 0.005)$

$= 8.843\ \mathrm{E{-}03\ W/m{-}^\circ C}$

$Q_C = 8.843\ \mathrm{E{-}03} * \frac{(62 - 31.5)}{(2.1)/100}$

$= 12.84\ \mathrm{W/m^2}$.

The lower bound value of $h = Q_C/(T_W - T_V) = 0.43\ \mathrm{W/m^2{-}^\circ C}$

(ii) at 298 seconds

$T_W = 106^\circ C$ $T_V = 47.5^\circ C$

$T_m = 76.75^\circ$ $dr = 2.1$ cm

$K_V = 0.007 * \mathrm{Exp}(76.75 * 0.005)$

$= 0.010274 \text{ W/m-}^{\circ}\text{C}$

$Q_C = \dfrac{(106 - 47.5) \times 100}{2.1}$

$= 28.64 \text{ W/m}^2$

The lower bound values of $h = 28.64/(106 - 47.5)$

$= 0.49 \text{ W/m}^2\text{-}^{\circ}\text{C}$

(iii) at 375.11 seconds

$T_W = 132^{\circ}\text{C}$ $\qquad T_V = 74.8^{\circ}\text{C}$

$T_m = 102.4^{\circ}\text{C}$ $\qquad dr = 2.1 \text{ cm}$

$K_V = 0.007 * \mathrm{Exp}(103.4 * 0.005)$

$= 0.01174 \text{ W/m-}^{\circ}\text{C}$

$Q_C = \dfrac{(132.0 - 74.8) \times 100}{(2.1)}$

$= 31.979 \text{ W/m}^2$

The lower bound value of $h = 0.56 \text{ W/m}^2\text{-}^{\circ}\text{C}$

From these values, it, is evident that the conduction heat transfer in the vapour space is negligible.

III.3.2 Radiation Heat Transfer From the Vapour Space Wall to the Liquid Surface in the UNB Vessel

The internal radiation from the vapour space wall to the liquid surface is given by

$$Q_{RI} = \frac{\sigma(T_W^4 - T_L^4)}{\dfrac{1-\varepsilon_W}{\varepsilon_W} + \dfrac{1}{F_{W-L}} + \dfrac{1-\varepsilon_L}{\varepsilon_L}\left(\dfrac{A_W}{A_L}\right)}$$

$A_L = 2(r\sin\theta)L$

$A_W = 2(r\theta)L$

UNB Vessel: (Data is taken from run number 1.)

(a) For 76% full, $Q_{IN} = 65\ kW/m^2$, PRV orifice = 1/4" ⌀

$\varepsilon_W = 0.076$ [11], $\varepsilon_L = 0.7$ [11], $\theta = 58.9^\circ$

(i) at 114.47 seconds

$T_W = 37.133^\circ C$ $\qquad T_L = 24.497^\circ C$

$A_L = 0.10764\ m^2$ $\qquad F_{W-L} = A_L/A_W$

$A_W = 0.12933\ m^2$ $\qquad = 0.8323$

$$\frac{A_W}{A_L} = 1.2015$$

$$Q_{RI} = \frac{5.669E\text{-}08((37.133 + 273)^4 - (24.497 + 273)^4)}{\frac{1-0.076}{0.076} + 1.2015 + \frac{1-0.7}{0.7}(1.2015)}$$

$$= 5.794\ W/m^2.$$

(ii) at 223.9 seconds

$T_W = 70.064^\circ C$ $\qquad T_L = 34.573^\circ C$

$$Q_{RI} = \frac{5.669E\text{-}08((70.064 + 273)^4 - (34.573 + 273)^4)}{\frac{1-0.076}{0.076} + 1.2015 + \frac{1-0.7}{0.7}(1.2015)}$$

$$= 20.03\ W/m^2.$$

(iii) at 414.73 seconds

$T_W = 130.19^\circ C$ $\qquad T_L = 58.503^\circ C$

$$Q_{RI} = \frac{5.669E\text{-}08((130.19 + 273)^4 - (58.503 + 273)^4)}{\frac{1-0.076}{0.076} + 1.2015 + \frac{1-0.7}{0.7}(1.2015)}$$

$$= 58.64\ W/m^2.$$

(iv) at 431.6 seconds

$T_W = 95.271^\circ C$ $\qquad T_L = 57.609^\circ C$

$$Q_{RI} = \frac{5.669E\text{-}08((95.271 + 273)^4 - (57.609 + 273)^4)}{\frac{1-0.076}{0.076} + 1.2015 + (\frac{1-0.7}{0.7})(1.2015)}$$

$$= 26.345\ W/m^2.$$

(b) UNB Vessel: (Data is taken from run number 2.)

$Q_{IN} = 65\ \text{kW/m}^2$. Liquid level = 58%

PRV orifice diameter = 1/4"

$\theta = 81.12^{\circ}$

$A_L = 2(r\sin\theta)L = 0.1232\ \text{m}^2$

$A_W = 2(r\theta)L = 0.1782\ \text{m}^2$

$F_{W-L} = \dfrac{A_L}{A_W} = 0.6978 \qquad \dfrac{A_W}{A_L} = 1.433$

(i) at 132.5 seconds

$T_W = 37.9^{\circ}\text{C} \qquad T_L = 23.378^{\circ}\text{C}$

$$Q_{RI} = \frac{5.669\text{E-}08((37.9 - 273)^4 - (23.378 - 273)^4)}{\frac{1-0.076}{0.076} - 1.433 - \frac{1-0.7}{0.7}(1.433)}$$

$= 6.494\ \text{W/m}^2$.

(ii) at 315.82 seconds

$T_W = 101.14^{\circ}\text{C} \qquad T_L = 42.896^{\circ}\text{C}$

$$Q_{RI} = \frac{5.669\text{E-}08((101.14 - 273)^4 - (42.896 - 273)^4)}{\frac{1-0.076}{0.076} - 1.433 - \frac{1-0.7}{0.7}(1.433)}$$

$= 38.457\ \text{W/m}^2$.

(iii) at 394.26 seconds

$T_W = 135.11^{\circ}\text{C} \qquad T_L = 53.56^{\circ}\text{C}$

$$Q_{RI} = \frac{5.669\text{E-}08((135.11 + 273)^4 - (53.56 + 273)^4)}{\frac{1-0.076}{0.076} + 1.433 + \frac{1-0.7}{0.7}(1.433)}$$

$= 65.32\ \text{W/m}^2$.

(iv) at 434.8 seconds

$T_W = 152.74^{\circ}\text{C} \qquad T_L = 59.75^{\circ}\text{C}$

$$Q_{RI} = \frac{5.669E-08((152.74 + 273)^4 - (59.75 + 273)^4)}{\frac{1-0.076}{0.076} + 1.433 + \frac{1-0.7}{0.7}(1.433)}$$

$$= 82.19\ W/m^2.$$

From these calculations, it is evident that the internal radiation in the UNB vessel is negligible.

III.3.3 Heat Transfer Coefficients in the Vapour Space

(i) For the Experimental Model 4.1 (UNB Vessel)

Note: All the data in the following calculations have been taken from Figs. 3.1 and 3.3. Only the data not presented in these figures is taken from run number 1.

(a) Average Vapour Space Wall Temperatures

At 186.98 seconds

TWVAV = 1/3 (54.783 + 57.817 + 61.595) = 58.07°C.

(b) Average Bulk Vapour Temperature

At 186.98 seconds

T_V = 1/5 (35.99 + 34.642 + 33.508 + 32.226 + 31.692)

= 33.62°C.

(c) Average Lava Temperature

At 186.98 seconds

TLAV = 1/2 (71.982 + 74.648) = 73.32°C.

(d) Average External Wall Temperature

At 186.98 seconds

T_{SS} = 1/4(22.153 + 21.629 + 22.25 + 21.823)

= 21.964°C.

(e) Heat Stored in the Steel

At 269.76 seconds, TWVAV = 84.44^{o}C

At 42.11 seconds, TWVAV = 23.68^{o}V

ρ_s = 7865.0 kg/m^2, C_{p_s} = 490 J/kg-^{o}C

t_s = 6.35E-03 m

$$Q_{ST} = 7865 * 490 * 6.35E\text{-}03 \frac{(84.44 - 23.68)}{(269.76 \quad 42.11)}$$

$$= 6800.42 \text{ W/m}^2.$$

(f) Heat Stored in the Lava Housing

At 260.76 seconds, TLAV = 120.945^{o}C

At 42.11 seconds, TLAV = 22.517^{o}C

ρ_{LA} = 2700 kg/m^3, $C_{P_{LA}}$ = 854.0 J/kg-^{o}C

t_{LA} = 0.03175 m

$$Q_{LA} = 2700 * 854 * 0.03175 \frac{(120.945 - 22.517)}{(260.76 - 42.11)}$$

$$= 32{,}956 \text{ W/m}^2.$$

(g) External Heat Radiation from the Lava Housing

At 186.98 seconds, T_{LA} = 346.32^{o}K

At 186.96 seconds, T_{SS} = 294.964^{o}K

ε_{LA} = 0.9, ε_{SS} = 0.66, A_{SS} = 0.4886 m^2

A_{LA} = 0.4213 m^2, σ = 5669E-08 W/m^2-^{o}K^4

$$F_{LA-SS} = \frac{A_{SS}}{A_{LA}} = 1.159$$

$$Q_{RELS} = \frac{5.669E\text{-}08((346.32)^4 - (294.964)^4)}{\frac{1-0.9}{0.9} + \frac{1}{1.159} + \frac{1-0.6}{0.6}\left(\frac{0.4213}{0.4886}\right)}$$

$$= 249.466 \text{ W/m}^2.$$

(h) Heat Transfer in the Vapour Space

$Q_{IN} = Q_{RELS} + Q_{ST} + Q_{LA} + Q_{CONV}$

$Q_{CONV} = Q_{IN} - Q_{RELS} - Q_{ST} - Q_{LA}$

$h(TWVAV - T_V) = Q_{IN} - Q_{RELS} - Q_{ST} - Q_{LA}$

Heat transfer coefficient is calculated as

$h(58.07 - 33.62) = 65000 - 249.466 - 6800.42 - 32,956$

Therefore, h at 186.98 seconds is given by

$h = 1022\ W/m^2$-°C for the DELTAT of 24.45°C.

This is plotted in Fig. 4.7.

(ii) For the Experimental Model 4.1 (Full-Scale Tank)

Note: All the data in the following calculations have been taken from the reference [2] for the full-scale tank car test.

(a) Average Wall Temperature

$T_W = 114.39^\circ C$ at 169.20 seconds

(b) Average Vapour Temperature

$T_V = 66.11^\circ C$ at 169.20 seconds

(c) Liquid Surface Temperature

$T_L = 42^\circ C$ at 169.2 seconds

(d) External Heat Radiation from the Vapour Space Wall

$\epsilon_s = 0.7$ [11] $\sigma = 5.669E{-}08\ W/m^2{-}K^4$

$Q_{RE} = \sigma \epsilon_s T_W^4$

$= 5.669E{-}08 * 0.7\ (114.39 - 273)^4$

$= 893.72\ W/m^2$.

(e) Heat Radiation from the Vapour Space Wall to the Liquid Surface

$\epsilon_W = 0.65$ [11], $\epsilon_L = 0.8$ [11]

The view factor is evaluated using eqn. (J) from the Appendix III.2

$$F_{W-L} = \frac{A_L}{A_W} = 0.8 \quad \frac{A_W}{A_L} = 1.25$$

$$Q_{RI} = \frac{5.669E-08((114.39 + 273)^4 - (42 + 273)^4)}{\frac{1-0.65}{0.65} + \frac{1}{0.8} - \frac{1-0.8}{0.8}(1.25)}$$

$$= 342.03 \text{ W/m}^2.$$

(f) Heat Stored in the Vapour Space Wall

$T_W = 150.5^{\circ}C$, at 211.5 seconds

$T_W = 25.4^{\circ}C$, at 42.6 seconds

$\rho_s = 7865 \text{ kg/m}^3$ $\quad C_{p_s} = 490 \text{ kJ/kg-}^{\circ}C$

$t_s = 0.0152$ m

$$Q_{ST} = 7865 * 490 * 0.0152 \frac{(150.5 - 25.4)}{(211.5 - 42.6)}$$

$$= 43{,}387.6 \text{ W/m}^2.$$

(g) Heat Transfer in the Vapour Space

Now using equation (4.5)

$$Q_{IN} = Q_{RE} + Q_{RI} + Q_{ST} + Q_{CONV}$$

$$Q_{CONV} = Q_{IN} - Q_{RE} - Q_{RI} - Q_{ST}$$

$$h(T_W - T_V) = Q_{IN} - Q_{RE} - Q_{RI} - Q_{ST}$$

$$h(114.39 - 66.11) = 109{,}000 - 893.72 - 342.03 - 43{,}387.6$$

Therefore, h at 169.2 seconds is given by

$$h = 1333.4 \text{ W/m}^2\text{-}^{\circ}C$$

This is plotted in Fig. 4.9.

(iii) For the Experimental Model 4.1 (Explosafe equipped vessel, NOVA). Note: All the data for the following calculations have been taken from reference [3].

(a) Average Wall Temperature

$T_W = 295.56^\circ C$, at 360 seconds

(b) Average Vapour Temperature

$T_V = 102.22^\circ C$, at 360 seconds

(c) Heat Stored in the Vapour Space Wall

At 420 seconds, $T_W = 332.78^\circ C$

At 1 second, $T_W = 26.11^\circ C$

$\rho_s = 7765.0\ kg/m^3$, $C_{p_s} = 490.0\ J/kg\text{-}^\circ C$

$t_s = 0.00762\ m$

$$Q_{ST} = 7765 * 490 * 0.00762 \frac{(332.78 - 26.11)}{(420.0 - 1.0)}$$

$$= 21,220\ W/m^2.$$

(d) External Heat Radiation from the Vapour Space Wall

$T_W = 295.56 - 273 = 568.56^\circ K$ at 360 seconds

$\varepsilon_s = 0.7$ [11]

$\sigma = 5.669 \times 10^{-8}\ W|m^2\text{-}k^4$

$$Q_{RE} = 5.669E\text{-}08 * 0.7 * (568.56)^4$$

$$= 4146.75\ W/m^2.$$

(e) Heat Transfer in the Vapour Space

$Q_{IN} = Q_{RE} + Q_{ST} + Q_{CONV}$ or $Q_{CONV} = Q_{IN} - Q_{RE} - Q_{ST}$

$h(T_W - T_V) = Q_{IN} - Q_{RE} - Q_{ST}$

Therefore, heat transfer coefficients are calculated as

$h(295.56 - 102.22) = 65{,}000 - 21{,}110 - 4146.75$

h at 360 seconds is:

$$h = 204.99 \text{ W/m}^2.$$

This is plotted in Fig. 4.10.

III.3.4 Nusselt and Fourier Numbers

(i) For the UNB Vessel

(a) $Nu = \dfrac{hL_c}{K_V}$

$$Fo = \frac{K_s\,\tau}{\rho_s C_{p_s} t_s^2}$$

$L_c = \dfrac{V_V}{A_h} = 0.0963$ m (calculated at four levels and then averaged)

From sample calculations of vapour space heat transfer in the UNB vessel at 186.98 seconds:

$T_V = 33.62^{\circ}$C . $h = 1022 \text{ W/m}^2\text{-}^{\circ}\text{C}$.

The thermal conductivity of Freon-11 vapour is:

$$\begin{aligned} K_V &= 0.007 * \text{Exp}(T_V * 0.005) \\ &= 0.007 * \text{Exp}(33.62 * 0.005) \\ &= 8.2813\text{E-03 W/m-}^{\circ}\text{C} \end{aligned}$$

∴ the Nusselt number at 186.98 seconds is:

$$Nu = \frac{1022 * 0.0963}{8.2813\text{E-03}} = 11884.4$$

$$Fo = \frac{K_s\,\tau}{\rho_s C_{p_s} t_s^2}$$

τ = 186.98 seconds, K_s = 15.1 W/m-°C

ρ_s = 7865 kg/m^3 $\qquad C_{p_s}$ = 490 J/kg-°C

t_s = 6.35E-03 m

$$\therefore \quad Fo = \frac{15.1 * 186.98}{7865 * 490 * (6.35E\text{-}03)^2} = 18 \cdot 17$$

(b) Prediction of Nusselt Number from the Correlation

At 186.98 seconds, Fo = 18.17

The empirical relation is:

$$Nu = 817575 * (Fo)^{-1.4932}$$

$$= 817579 * (18.17)^{-1.4932}$$

$$= 10766.12.$$

(ii) For the Full-Scale Vessel

(a) $L_c = \frac{V_v}{A_h} = 0.342$ m

From sample calculations (Appendix III.3.2)

T_V = 66.11°C, at 169.2 seconds

h = 1333.4 W/m^2-°C, at 169.2 seconds.

The thermal conductivity of propane vapour is:

$$K_V = -\ 1.390775E\text{-}08 + 3.251649E\text{-}06 * (T_v + 273)$$
$$+\ 2.407276E\text{-}07 * (T_V + 273)^2$$
$$-\ 1.610365E\text{-}10 * (T_V + 273)^3$$
$$= -\ 1.390775E\text{-}08 + 3.251649E\text{-}06 * (66.11 + 273)$$
$$+\ 2.407276E\text{-}07 * (66.11 - 273)^2$$
$$-\ 1.610365E\text{-}10 * (66.11 + 273)^3$$
$$= 0.0225 \text{ W/m-°C.}$$

At 169.2 seconds, the Nusselt number for the propane vapour is:

$$Nu = \frac{1333.4 * 0.342}{0.0225}$$

$$= 20262.82$$

$\rho_s = 7865\ kg/m^2$ $C_{p_s} = 490\ J/jg\text{-}^oC$

$t_s = 0.0152\ m$ $\tau = 169.2$ seconds

$k_s = 57.8\ W/m\text{-}^oC$

$$Fo = \frac{57.8 * 169.2}{7865 * 490 * (0.0152)^2}$$

$$= 10.983.$$

(b) Prediction of Nusselt Number from the Correlation

At 169.2 seconds

For the Fourier number Fo = 10.983.

$$Nu = 817579 * (Fo)^{-1.4932}$$

$$= 817579 * (10.983)^{-1.4932}$$

$$= 22,827.87.$$

III.3.5 Convection Heat Transfer in the Vapour Space of the UNB Vessel (an Alternate Method)

Note: All the data in the following calculations have been taken from Figs. 3.1, 3.3 and 4.6. Only the data not presented in these figures are taken from the Appendix III.

For the UNB Vessel: (Data from run number 1.)

$Q = 65\ kW/m^2$ PRV orifice = 1/4" ϕ

Liquid level = 76%.

(i) at 298.5 seconds

from Fig. 4.6

$$T_{WIRE} = 610.3^{o}C$$

$$T_{LA} = 222.0^{o}C$$

$$T_{W} = 98.0^{o}C$$

$$Tg = \frac{T_{LA} + T_{W}}{2} = 160^{o}C.$$

The heat radiation from the heater wire to the inner surface of the lava (boundary 1 as shown in Fig. 4.5 is:

$$Q_{RLA} = \sigma(T_{WIRE}^{4} - T_{LA}^{4})$$

$$= 5.669E\text{-}08((610.3 - 273)^{4} - (222 - 273)^{4})$$

$$= 31106.2\ W/m^{2}.$$

The heat radiation from the heater wire to the outer surface of the inner vessel is:

$$Q_{RS} = \sigma(T_{WIRE}^{4} - T_{W}^{4})$$

$$= 5.669E\text{-}08((610.3 - 273)^{4} - (98.0 - 273)^{4})$$

$$= 33435.5\ W/m^{2}$$

and the heat conducted through the argon gas in the gap between the lava and the inner vessel is

$$Q_{CONDG} = kg(T_{WIRE} - Tg)/drg.$$

$kg = 0.00635\ W/m\text{-}^{o}C$

$drg = 0.0063\ m$

$$Q_{CONDG} = \frac{0.00635(610.3 - 160)}{0.0063}$$

$$= 453.87\ W/m^{2}.$$

Since Q_{RS} is the heat input on the boundary 2 of Fig. 4.5 and the energy balance from eqn. (4.13) is:

$$Q_{RS} = Q_{ST} + Q_{COND} + Q_{CONV}$$

T_{WV} = 95.6°C, at 48° with the vertical

T_{WL} = 44.5°C, at 78° with the vertical

k_s = 15.1 W/m-°C $\theta = 78-48 = 30^\circ = 0.5236$ rads

r = 0.1905 m.

The heat conducted circumferentially in the tank wall from the vapour space to the liquid at the interface is:

$$Q_{COND} = \frac{k_s(T_{WV} - T_{WL})}{r}$$

$$= \frac{15.1(95.6 - 44.5)}{0.1905 * 0.5236} = 7735.8 \text{ W/m}^2.$$

T_W = 86.8°C, at 260.76 seconds

T_W = 114.9°C, at 335.99 seconds

ρ_s = 7865 kg/m^3 C_{P_s} = 490 J/kg-°C

t_s = 0.00635 m.

Therefore, the heat stored in the steel wall in the vapour space at 298.5 seconds is:

$$Q_{ST} = 7865 * 490 * 0.00635 * \frac{(114.9 - 86.8)}{(335.99 - 260.76)}$$

$$= 9140.7 \text{ W/m}^2$$

Now using eqn. (4.13), we have

$$Q_{CONV} = Q_{RS} - (Q_{ST} + Q_{COND})$$

$$= 33435.5 - (9140.7 + 7735.8)$$

$$= 16559\ W/m^2.$$

From the heat transfer model given in section 4.1, the convective heat transfer at 298.5 seconds is:

$$h = 376.4\ W/m^2 \quad \text{and} \quad \Delta T = 49.63^\circ C.$$

So

$$Q_{CONV} = 18678.63\ W/m^2.$$

Therefore, the convection heat transfer evaluated by the model 4.1 has 11% higher value. The heat radiated to the lava blocks and stored is as follows:

$T_{LA} = 193.87^\circ C$, at 260.76 seconds

$T_{LA} = 250.83^\circ C$, at 335.99 seconds

$$Q_{LA} = 2700 * 854 * 0.0203 \frac{(250.83 - 193.87)}{(335.99 - 260.76)}$$

$$= 35508.4\ W/m^2$$

and

$$Q_{RLA} = 31106.2\ W/m^2.$$

Therefore, Q_{LA} has 12% higher value than Q_{RLA}.

(ii) At 335.99 seconds

$T_{WIRE} = 614^\circ C$

$T_{LA} = 251^\circ C$

$T_W = 114^\circ C$

$$Tg = \frac{T_{LA} + T_W}{2} \quad \frac{251 + 114}{2} = 182.5^{\circ}C$$

$$Q_{RLA} = \sigma(T_{WIRE}^4 - T_{LA}^4)$$

$$= 5.669E\text{-}08((614 + 273)^4 - (251 + 273)^4)$$

$$= 30849 \text{ W/m}^2$$

$$Q_{RS} = \sigma(T_{WIRE}^4 - T_W^4)$$

$$= 5.669E\text{-}08((614 + 273)^4 - (114 + 273)^4)$$

$$= 33820 \text{ W/m}^2$$

$$Q_{CONDG} = \frac{kg(T_{WIRE} - Tg)}{drg}$$

$$= \frac{0.00635(614 - 182.5)}{0.0063} = 435 \text{ W/m}^2$$

at 335.99 seconds

T_{WV} = 107.4 seconds, at 48° with the vertical

T_{WL} = 49.2 seconds, at 78° with the vertical

$$Q_{COND} = \frac{k_s(T_{WV} - T_{WL})}{r\theta}$$

$$= \frac{15.1(107.4 - 49.2)}{0.1905 * 0.5236}$$

$$= 8812 \text{ W/m}^2.$$

T_W = 98°C, at 298.5 seconds

T_W = 131°C, at 375.11 seconds

$$Q_{ST} = 7865 * 490 * 0.00635(131 - 98)/(375.11 - 298.5)$$

$$= 10541 \text{ W/m}^2.$$

Using eqn. (4.13) again, we have

$$Q_{CONV} = Q_{RS} - (Q_{ST} + Q_{COND})$$
$$= 33820 - (10541 + 8812)$$
$$= 14467 \text{ W/m}^2.$$

The convective heat transfer from the model 4.1 at 335.99 seconds is

$$h = 288.87 \text{ W/m}^2\text{-}^{\circ}\text{C}$$
$$\Delta T = 57.14^{\circ}\text{C}.$$

So $Q_{CONV} = 16506 \text{ W/m}^2$.

Therefore, the convective heat transfer evaluated by the model 4.1 has 12% higher value. The heat radiated to the lava blocks and stored, is as follows:

$T_{LA} = 222.34^{\circ}\text{C}$, at 298.5 seconds

$T_{LA} = 280.98^{\circ}\text{C}$, at 375.11 seconds

$$Q_{LA} = 2700 * 854 * \frac{(280.98 - 222.34)}{(375.11 - 298.5)}$$
$$= 35828 \text{ W/m}^2.$$

$$Q_{RLA} = 30849 \text{ W/m}^2.$$

Therefore, Q_{LA} has 13% higher value than Q_{RLA}.

III.3.6 Verification of the Assumption

T_W (outer surface) = T_W (inner surface)

The energy balance on the vapour space wall is given as:

$$Q_{RS} = Q_{COND} + Q_{CONDR} + Q_{ST}$$

$$= \frac{k_s(T_{WV}-T_{WL})}{r\theta} + \frac{k_s(T_{WO}-T_{WI})}{t_s} + \rho_s C_{p_s} t_s \frac{(T^{(n+1)}-T^{(1)})}{(\tau^{(n+1)}-\tau^{(1)})}$$

(i) At 298.5 seconds (values are taken from Appendix III.3.5)

$Q_{RS} = 33435.5\ \mathrm{W/m^2}$

$Q_{COND} = 7735.8\ \mathrm{W/m^2}$

$Q_{ST} = 9140.7\ \mathrm{W/m^2}$

$$33435.5 = 7735.8 + \frac{15.1(T_{WO} - T_{WI})}{6.35\mathrm{E}{-03}} + 9140.7$$

$$33435.5 = 7735.8 + 2377.95\ (T_{WO} - T_{WI}) + 9140.7$$

$$(T_{WO} - T_{WI}) = 6.9636^{\circ}\mathrm{C}.$$

(ii) At 336 seconds

$Q_{RS} = 33820\ \mathrm{W/m^2}$

$Q_{COND} = 8812\ \mathrm{W/m^2}$

$Q_{ST} = 10541\ \mathrm{W/m^2}$

$$6.08^{\circ}\mathrm{C} = T_{WO} - T_{WI}$$

From this analysis, it is verified that the assumption of T_W(outside) = T_W(inside) is quite good.